Verification of Translation

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Tokyo, Japan

This 5th day of June, 2003

Takeo Noguchi
Japanese Patent Attorney

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[Inventor]

[Domicile] c/o KOMATSU LIMITED, 1200 Manda, Hiratsuka-shi, Kanagawa-ken

[Name] Toshihiro TABUCHI

[Inventor]

[Domicile] c/o KOMATSU LIMITED, 1200 Manda, Hiratsuka-shi, Kanagawa-ken

[Name] Kouichi ISHIDA

[Inventor]

[Domicile] c/o KOMATSU LIMITED, 1200 Manda, Hiratsuka-shi, Kanagawa-ken

[Name] Hiroyuki MIZUKAMI

[Inventor]

[Domicile] c/o KOMATSU LIMITED, 1200 Manda, Hiratsuka-shi, Kanagawa-ken

[Name] Masayuki TAKASHIRI

[Applicant]

[ID Number] 000001236

[Name] KOMATSU LIMITED

[Agent]

[ID Number] 100091948

[Patent Attorney]

[Name] Takeo NOGUCHI

[Official Fee]

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[DOCUMENT NAME] SPECIFICATION

[TITLE OF THE INVENTION] SURFACE TREATMENT APPARATUS

[SCOPE OF CLAIMS]

[Claim 1] A surface treatment apparatus for making raw material gas plasma by generating plasma, in a casing provided with plasma generation means, a raw material gas inlet and a substrate support table, by the plasma generation means and giving plasma treatment to a surface of a substrate placed on said substrate support table, characterized in that:

said casing is defined into two chambers, a plasma generation chamber provided with said plasma generation means and a substrate treatment chamber provided with said substrate support table;

said substrate treatment chamber and said plasma generation chamber are connected through one or more plasma nozzles; and

at least one of said plasma nozzles is made a hollow discharge generation area.

[Claim 2] A surface treatment apparatus for making raw material gas plasma by generating plasma, in a casing provided with a pair of plasma generation electrodes consisting of an anode and a cathode, a raw material gas inlet and a substrate support table, by the plasma generation electrodes and giving plasma treatment to a surface of a substrate placed on the substrate support table, characterized in that:

said casing is defined into two chambers, a plasma generation chamber provided with said plasma generation means and a substrate treatment chamber provided with said substrate support table;

said substrate treatment chamber and said plasma generation chamber are connected through one or more plasma nozzles; and

said cathode electrode has one or more hollow cathode discharge generation areas.

[Claim 3] A surface treatment apparatus for making raw material gas plasma by generating plasma, in a casing provided with a pair of plasma generation electrodes consisting of an anode and a cathode, a raw material gas inlet and a substrate support table, by the plasma generation electrodes and giving plasma treatment to the surface of a substrate placed on the substrate support table, characterized in that:

said casing is defined into two chambers, a plasma generation chamber provided with said plasma generation electrodes and a substrate treatment chamber provided with said substrate support table;

said substrate treatment chamber and said plasma generation chamber are connected through one or more plasma nozzles;

at least one of said plasma nozzles is made a hollow discharge generation area; and

said cathode electrode has one or more hollow cathode discharge generation areas.

[Claim 4] A surface treatment apparatus according to one of claims 1 to 3, wherein an opening width W(A) of the smallest portion on at least one of the plasma nozzles is set in a range satisfying either of $W(A) \leqq 5L(e)$ or $W(A) \leqq 20X$:

where L(e) is an electron mean free path in respect to atom or molecular species (active species) of the smallest diameter among raw material gas species and electrically neutral atom or molecular species (active species) produced there from by decomposition, under the desired plasma generation conditions; and

X is a thickness of a sheath layer generated under the desired plasma generation conditions.

[Claim 5] A surface treatment apparatus according to claim 2 or 3, wherein said cathode electrode includes one or more recesses on a surface opposed to the anode electrode and, at least one of the recesses is made the hollow cathode discharge generation area.

[Claim 6] A surface treatment apparatus according to claim 2 or 3, wherein said cathode electrode is hollow-shaped, the cathode electrode has one or more through holes at a portion opposed to the anode electrode and, at least one of said through holes is made the hollow cathode discharge generation area.

[Claim 7] A surface treatment apparatus according to claim

5 or 6, wherein an opening width W(C) of the smallest portion of the recess or the through hole is set in a range satisfying either of $W(C) \leqq 5L(e)$ or $W(C) \leqq 20X$:

where L(e) is an electron mean free path in respect to atom or molecular species (active species) of the smallest diameter among raw material gas species and electrically neutral atom or molecular species (active species) produced therefrom by decomposition, under the desired plasma generation conditions; and

X is a thickness of a sheath layer generated under the desired plasma generation conditions.

[Claim 8] A surface treatment apparatus according to one of claims 1 to 3, wherein a magnetic field is formed in the vicinity of said plasma nozzle and/or said recess or the through hole.

[Claim 9] A surface treatment apparatus according to claim 6, wherein a hollow inside of the hollow-shaped cathode electrode is the hollow cathode discharge generation area

[Claim 10] A surface treatment apparatus according to claim 9, wherein a height H of the hollow inside of the hollow-shaped cathode electrode is set in a range satisfying either of $H \leqq 5L(e)$ or $H \leqq 20X$:

where L(e) is an electron mean free path in respect to atom or molecular species (active species) of the smallest diameter among raw material gas species and electrically

neutral atom or molecular species (active species) produced therefrom by decomposition, under the desired plasma generation conditions; and

X is a thickness of a sheath layer generated under the desired plasma generation conditions.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Field of the Invention]

The present invention relates to various surface treatments to a substrate and, especially to a surface treatment apparatus appropriate for forming a film on a substrate, and more particularly to a surface treatment apparatus for forming a crystalline thin film of high quality at a high speed.

[0002]

[Prior Arts]

In a conventional parallel flat plate type plasma CVD (Chemical Vapor Deposition) apparatus for film formation processing, a pair of flat plate form plasma generation electrodes are installed opposed in parallel in a casing. One of the plasma generation electrodes functions also as a substrate support table and moreover, the apparatus is provided with a heater to adjust a substrate temperature to a temperature appropriate for vapor growth. If an electric power is applied between the both plasma generation electrodes by a high

frequency power supply (power source of 13.56 MHz) with a substrate placed on the one electrode, discharge is generated between these electrodes. Plasma is generated by this discharge, and the raw material gas such as monosilane gas is made plasma to form a silicone film on the substrate surface.

[0003]

Such conventional parallel flat plate type plasma CVD apparatus has advantage of being able to form a film on a substrate of large area by a single film forming process, by enlarging the area of the flat plate type plasma generation electrode where the substrate is placed. However, in the conventional parallel flat plate type plasma CVD apparatus, the raw material gas made plasma by both the plasma generation electrodes is dispersed uniformly in a film formation gas processing chamber, and only a portion thereof contributes to the film formation on the substrate disposed on the electrode. Therefore, the raw material use efficiency is low and, for example, if an amorphous silicone thin film or a fine crystalline silicone thin film is to be formed on the substrate, the film formation speed is late as about 1 to 2 Å/sec despite a high input electric power. As the consequence, it takes much more time to manufacture a semiconductor device relatively large in thickness such as a solar cell, resulting in low throughput and high costs.

[0004]

Therefore, in order to increase the film formation speed, it is proposed to increase the input electric power by the high frequency power source. However, electric current passes between both plasma generation electrodes, and the number of charged particles in the plasma depends on intensity of the current. The charged particles are biased to plus with respect to each electrodes, are accelerated toward each electrode of lower potential and the substrate placed on the electrode and collides directly against the substrate. The film quality of the substrate is deteriorated by the damage due to collision of charged particles against the substrate. Number and energy of collision of the charged particles raises along increase in applied electricity, and deterioration of the film by damage from the collision of the charged particles becomes remarkable. Moreover, according to the increase of high frequency power by the high frequency power supply, a quantity of fine particles are generated in the vapor phase, and the film quality will be deteriorated considerably by the fine particles.

[0005]

Consequently, in the conventional parallel flat plate type plasma CVD apparatus, input electricity (input power) should be limited and the electric current should be weakened in order to avoid the film quality deterioration due to damage by the charged particles or fine particles. In other words, there is substantially an upper limit of input electric power,

and it has been impossible to increase the film formation speed more than a certain level.

[0006]

On the other hand, the formation apparatus of photoelectromotive device on a band shape member, which is a running element to be treated, disclosed in Japanese Patent Laid-Open Publication No. 11-145492, the cathode electrode potential during glow discharge generation is kept positive of +30V or more in respect to the earthed anode electrode including the band shaped member, by making the surface area in the discharge space of the high frequency power impression electrode (cathode electrode) larger than the surface area in the discharge space of whole the anode electrode including the band shaped member. Moreover, a plurality of divider shaped electrodes orthogonal to the running direction of the band shaped member are disposed on the cathode electrode to generate discharge between adjacent divider shaped electrodes also. Thus, the material gas excitation and decomposition reaction are accelerated at the anode electrode side including band shaped member, by keeping the cathode electrode positive of +30V or more in respect to the band shaped member and the anode electrode and, at the same time, composing such a cathode electrode structure including divider shaped electrodes as mentioned above.

[0007]

It can be admitted that the formation apparatus of the photoelectromotive device disclosed in the foregoing publication is supposed to improve the film formation speed, by accelerating the material gas excitation and decomposition reaction at the anode electrode side including the band shaped member. However, damage due to the charged particle collision persists, because the glow discharge is still generated in the space between the band shaped member and the cathode electrode.

[0008]

Therefore, in the thin film formation apparatus disclosed, for example, in Japanese Patent Laid-Open Publication No. 61-32417, an activated gas generator comprising a division chamber having a pair of opposed plasma generation electrodes is disposed in a vacuum chamber for forming a thin film on the substrate. A single narrow port is formed on one wall section of the activated gas generator for spouting out activated gas into the vacuum chamber. In addition, the substrate is supported in the vacuum chamber at a position opposed to the narrow port.

[0009]

In the thin film formation apparatus, plasma is produced by applying high frequency power to the pair of plasma generation electrodes and generating glow discharge between both electrodes. Raw material gas introduced in the activated gas generator is decomposed by this plasma. At this moment,

activated raw material gas spouts out from the narrow port towards the substrate, by reducing the vacuum degree of the vacuum chamber lower than the activated gas generator by 2 to 3 places to the right through the adjustment of the vacuum pump disposed in the vacuum chamber and the conductance of the narrow port.

[0010]

Thus, the film formation speed can be increased without increasing the input electric power in the thin film formation apparatus wherein plasma generation electrodes are disposed in the activated gas generator defined in the vacuum chamber for thin film formation and raw material gas activated in the activated gas generator is actively jetted towards the substrate. Moreover, even when a stronger plasma is generated by increasing the input electric power, as the plasma generation electrodes are disposed in the defined activated gas generator, the glow discharge between both electrodes have no chance to damage the substrate. Therefore, it is possible to increase further the film formation speed by increasing the input electric power. In addition, high quality thin film can be formed faster than before, as the thin film crystallization is accelerated, despite the film formation speed-up.

[0011]

[Problems to be Solved by the invention]

Thus, the film formation speed has certainly been

increased by dividing the plasma generation chamber and the film formation processing chamber; however further increase of film formation speed is desired, and especially, a high speed formation of fine crystalline thin film for the application of solar cell or the like is strongly expected.

In order to solve such a problem, the present invention has an object to provide a surface treatment apparatus that can treat a surface with high speed and high quality.

[0012]

[Means to Solve the Problem]

To solve such problem, invention according to claim 1 of the present application provides a surface treatment apparatus for making raw material gas plasma by generating plasma, in a casing provided with plasma generation means, a raw material gas inlet and a substrate support table, by the plasma generation means and giving plasma treatment the surface of a substrate placed on the substrate support table, characterized in that the casing is defined into two chambers, plasma generation chamber provided with the plasma generation means and a substrate treatment chamber provided with the substrate support table, the substrate treatment chamber and the plasma generation chamber are connected through one or more plasma nozzles, and a hollow discharge generation area is made in at least a portion of the hollow inside.

[0013]

As the plasma generation means, means of discharge by a pair of plasma generation electrodes consisting of a cathode and an anode, discharge having electrodes of three poles or more, microwave discharge, capacitance coupling type discharge, inductive coupling type discharge, PIG discharge, electron beam excitation discharge or others can be adopted.

[0014]

The plasma nozzle is formed in the partition wall between the substrate treatment chamber and a plasma generation chamber. The hollow discharge generated at this plasma nozzle becomes hollow cathode discharge or hollow anode discharge by the potential of the plasma nozzle.

[0015]

Meanwhile, when a pair of plasma generation electrodes comprising a cathode and an anode are adopted as the plasma generation means, either one of these electrodes may be used as the partition wall. For example, when the anode electrode is used as the partition wall and the plasma nozzle is formed on the anode electrode, the hollow discharge becomes hollow anode discharge. When the cathode electrode is used as the partition wall and the plasma nozzle is formed in the cathode electrode, the hollow discharge becomes hollow cathode discharge.

[0016]

Further, invention according to claim 2 of the present

application provides a surface treatment apparatus for making raw material gas plasma by generating plasma, in a casing provided with a pair of plasma generation electrodes consisting of an anode and a cathode, a raw material gas inlet and a substrate support table, by the plasma generation electrodes and giving plasma treatment to the surface of a substrate placed on the substrate support table, characterized in that the casing is defined into two chambers, plasma generation chamber provided with the plasma generation means and substrate treatment chamber provided with the substrate support table, the substrate treatment chamber and the plasma generation chamber are connected through one or more plasma nozzles and the cathode electrode has one or more hollow cathode discharge generation areas.

[0017]

In addition, invention according to claim 3 of the present application provides a surface treatment apparatus for making raw material gas plasma by generating plasma, in a casing provided with a pair of plasma generation electrodes consisting of an anode and a cathode, a raw material gas inlet and a substrate support table, by the plasma generation electrodes and giving plasma treatment to the surface of a substrate placed on the substrate support table, wherein the casing is defined into two chambers, plasma generation chamber provided with the plasma generation means and a substrate treatment chamber

provided with the substrate support table, the substrate treatment chamber and the plasma generation chamber are connected through one or more plasma nozzles, at least one of the plasma nozzles is made a hollow discharge generation area and the cathode electrode has one or more hollow cathode discharge generation areas.

[0018]

Meanwhile, in the present invention, an electrode at a side to which main electricity for discharge is applied is set as the cathode electrode and an electrode opposing the cathode electrode is set as the anode electrode.

In the invention according to claims 2 and 3 in which a pair of plasma generation electrodes are adopted as the plasma generation means, the plasma generation chamber and the substrate treatment chamber can be defined by the anode electrode or the cathode electrode. At this time, the plasma nozzle is formed at an electrode defining the plasma generation chamber and the substrate treatment chamber. Alternatively, a partition plate defining the plasma generation chamber and the substrate treatment chamber can be provided and the plasma nozzle can be formed at the partition plate.

[0019]

When surface treatment is applied by the surface treatment apparatus, plasma is first generated in the plasma generation chamber by the plasma generation means or the plasma

generation electrodes. At that time, the plasma in the plasma generation chamber flows from the plasma nozzle to the substrate treatment chamber by adjusting the pressure in the substrate treatment chamber lower than that in the plasma generation chamber. Raw gas is introduced to the plasma while the plasma is generated in the plasma generation chamber, is spouted to the substrate treatment chamber, and reaches the surface of the substrate. The raw gas is activated by the plasma, active species contributing to the surface treatment is generated, the active species reaches to the surface of the substrate in the treatment chamber by means of plasma flow, and surface treatment such as etching and film formation is applied to the substrate.

[0020]

According to the invention of claim 1 of the present application, it is important to generate hollow discharge on at least one of the plasma nozzles. As new plasma is generated at the plasma nozzle by this hollow discharge, the density of plasma directed to the substrate treatment chamber is increased. Further, as for plasma generated in the plasma generation chamber, the energy of charged particles (electron or ion) in the plasma decreases when it passes through the plasma nozzle where hollow discharge occurs. Through the electron energy drop, electrons will have an appropriate energy intensity, strong enough to generate active species contributing to the

surface treatment from raw material gas, and moderated not to generate often ions damaging the substrate surface by collision, resulting in increase of active species without increasing the ions. Moreover, substrate damage due to collision of these ions can be mitigated by reducing the energy of the ions in the plasma.

[0021]

Thus, the surface treatment can be accelerated, because the active species contributing to the surface treatment increase by the plasma density elevation due to the hollow discharge. Moreover, substrate surface deterioration can be controlled and high quality surface treatment can be realized, by decreasing the energy of ions existing in the plasma and damaging the substrate by collision.

[0022]

In the invention according to claim 2 of the present application, it is important to generate hollow cathode discharge at the cathode electrode. Plasma is newly generated at the hollow cathode discharge generation area by generating hollow cathode discharge. Consequently, density of plasma introduced to the substrate treatment chamber increases and the number of active species contributing to the surface treatment increases, thereby further increasing speed of the surface treatment.

[0023]

Further, according to the invention of claim 3 of the present application, both of the aforementioned hollow discharge and hollow cathode discharge are generated. Consequently, the aforementioned respective functional effects of both of the hollow discharge and the hollow cathode discharge are provided, further increasing the surface treatment speed and quality.

[0024]

As the substrate, glass, organic film, SUS or other metals can be used. Further, the surface treatment apparatus of the present invention can be used for various surface treatments such as film formation, ashing and etching, and further, it can particularly preferably used for formation of silicone thin film such as crystalline silicone or oxide film.

[0025]

When a number of the plasma nozzle are to be disposed, hollow discharge generated at all of these nozzles is preferable, as it allows to form an uniform thin film at a high speed even for a large area substrate.

[0026]

The raw material gas inlet may be opened in the plasma generation chamber, or, only carrier gas may be introduced in the plasma generation chamber, and the raw material gas inlet can be provided at the side face of the plasma nozzle. Moreover, the raw material gas inlet can be opened by using, for example,

a raw material gas introduction pipe, to introduce the raw material gas between the plasma nozzle and the substrate in the substrate treatment chamber. When the raw material gas inlet is opened at the plasma nozzle or in the substrate treatment chamber, the raw material gas is plasmatized by plasmatized carrier gas passing through the nozzle. In this case, the inner wall surface of the plasma generation chamber will not be contaminated with the raw material gas.

[0027]

The plasma generation electrode can be applied to direct current to high frequency power by connecting to a direct current source or high frequency source, but especially, it is preferable to input high frequency power. Further, bias can be applied to the cathode electrode and the anode electrode respectively by DC or AC power supply.

[0028]

In order to generate hollow discharge at the plasma nozzle, preferably, an opening width W(A) of the smallest portion on at least one of the plasma nozzles is set in a range satisfying either of $W(A) \leqq 5L(e)$ or $W(A) \leqq 20X$. L(e) is an electron mean free path in respect to atom or molecular species (active species) of the smallest diameter among raw material gas species and electrically neutral atom or molecular species (active species) produced therefrom by decomposition, under the desired plasma generation conditions. And X is a thickness

of a sheath layer generated under the desired plasma generation conditions. In addition, it is preferable to set the opening width W(A) of the smallest portion on at least one of the plasma nozzles in a range satisfying $X/5 \leqq W(A)$.

[0029]

The electron mean free path in respect to the atom in the dispersion with electron and gas molecular (including atom) depends on gas pressure, atom and molecular dispersion cross section area and temperature, and the plasma generation conditions include these gas pressure, atom and molecular dispersion cross section area, temperature and the like.

[0030]

Hollow glow discharge can be generated efficiently at the plasma nozzle, and at the time, plasma can be spouted out efficiently from the nozzle, by setting the opening width W(A) of the plasma nozzle in the range mentioned above.

[0031]

In the present invention, the opening width W(A) of the plasma nozzle corresponds to its diameter when the opening shape of the plasma nozzle is circular, and it corresponds to its short side length dimension when it is rectangular or slit formed. That is, the shortest dimension portion of this opening shape is taken as the opening width W(A). A shape that can intake plasma of the plasma generation chamber positively into the nozzle, and diffuse and spout plasma in the substrate

treatment chamber at a desired angle may be adopted as the shape of the plasma nozzle. Such shape includes cylindrical form having a circular cross-section, truncated cone increasing the diameter from the plasma generation chamber to the substrate treatment chamber, and combination thereof, and further a shape whose diameter of downstream side half increases downwards. And moreover, it may be a prism having a rectangular cross-section or a slit form as mentioned above.

[0032]

According to the invention of claim 5 of the present application, the cathode electrode has one or more recesses on a surface opposed to the anode electrode and, at least one of the recesses is made the hollow cathode discharge generation are.

Meanwhile, according to the invention of claim 6 of the present application, the cathode electrode is hollow-shaped, the cathode electrode has one or more through holes at a portion opposed to the anode electrode and, at least one of said through holes is made the hollow cathode discharge generation area.

[0033]

Thus, the surface area of the cathode electrode substantially in contact with plasma increases by forming recesses on the cathode electrode or by making the cathode electrode hollow-shaped and forming through holes, and by making these recesses or through holes hollow cathode discharge

generation areas. As a result, the cathode electrode potential (self bias) during the glow discharge generation can be brought to the plus direction, and input electric power consumption in the vicinity of the grounded anode electrode, namely raw material gas excitation and decomposition reaction are accelerated, resulting in surface treatment rate improvement.

[0034]

Such self bias control leads to the plasma space potential control and can adjust intentionally the extent of damage due to collision of ion to the substrate. Consequently, for example, when the film formation treatment is to be performed, the crystallinity of its crystalline thin film can be controlled.

[0035]

In order to generate hollow cathode discharge efficiently at the recess or the through hole, in the invention according to claim 7 of the present application, an opening width W(C) of the smallest portion of the recess or the through hole is set in a range satisfying either of $W(C) \leqq L(e)$ or $W(C) \leqq 20X$. L(e) is an electron mean free path in respect to atom or molecular species (active species) of the smallest diameter among raw material gas species and electrically neutral atom or molecular species (active species) produced therefrom by decomposition, under the desired plasma generation conditions

and X is a thickness of a sheath layer generated under the desired plasma generation conditions.

[0036]

Besides, in the invention according to claim 8 of the present application, a magnetic field is formed in the vicinity of the plasma nozzle and/or the recess or the through hole, that is, in the vicinity of the plasma nozzle and/or the recess, or in the vicinity of the plasma nozzle and/or the through hole. The "proximity" includes the inside of the plasma nozzle, recess and through hole, or the periphery and proximity of the opening of the plasma nozzle, recess and through hole. Besides, the magnet is preferably disposed so that the magnetic line of flux of its magnetic field becomes parallel to the axial direction of the plasma nozzle, recess and through hole.

[0037]

The magnetic field intensity is preferably 1 to 2000 mT at the central portion of the plasma nozzle and/or the recess or the through hole, or in the hollow inside and more preferably, 5 to 500 mT. Also, the magnetic field intensity is preferably 2 to 2000 mT, and more preferably, 5 to 1000 mT at the inner wall face and in the vicinity of the plasma nozzle and/or the recess or the through hole.

[0038]

Such magnetic field disposition allows electrons to remain for a long time in the plasma nozzle where hollow

discharge occurs or in the vicinity thereof, inside the recess or through hole where hollow cathode discharge occurs or in the vicinity thereof, by adjusting the electron orbit, and the generation of active species contributing to the surface treatment is accelerated. Consequently, the surface treatment speed increases further. The electron energy does not change by this magnetic field and, therefore, non adversely affecting ion is generated by the electron energy increase, allowing to maintain a high quality surface treatment.

[0039]

In addition, it is preferable to protrude a nozzle element on at least one side opening edge of the plasma nozzle and/or the recess or the through hole. The center line of the nozzle element may be aligned with the axial direction of the plasma nozzle and/or the recess or the through hole, or the center line of the nozzle element may be disposed making an angle in respect to the axial direction of the plasma nozzle and/or the recess or the through hole. Besides, the nozzle element shape may be a cylinder having a constant cross section form, or a cylinder reducing or increasing gradually in its cross section dimensions. Moreover, a tubular nozzle element may be disposed in spiral.

[0040]

By providing the protruding nozzle element at the plasma nozzle and/or the recess or the through hole, the length

dimension of the plasma nozzle and/or recess, through hole can be set as desired without increasing unnecessarily the thickness dimension of members composing the plasma nozzle or the cathode electrode, and the plasma density increases and the surface treatment speed is improved, because the generation area of the hollow discharge or the hollow cathode discharge is widened by increasing this length.

[0041]

Moreover, the nozzle length of the nozzle element is preferably inconstant. In other words, at the plasma nozzle and/or recess, or plasma nozzle and/or through hole, the length of all nozzle elements thereof is not necessarily uniform, but it may vary conveniently. Thus, by changing the nozzle element length, the intensity of plasma arriving at the substrate can be uniformed all over the surface of this substrate.

[0042]

According to invention of claim 9 of the present invention, a hollow inside of the hollow-shaped cathode electrode is the hollow cathode discharge generation area.

By generating the hollow cathode discharge also at the hollow inside in this way, plasma density can be further increased. Moreover, by in creasing the surface area of the cathode electrode in contact with the plasma, self bias can be adjusted further to a potential of a plus direction. Consequently, excitation and decomposition reaction of raw gas

are remarkably enhanced and speed of the surface treatment also increases.

[0043]

It is preferable to provide one or more partitions extending in a height direction of the hollow inside in the hollow-shaped cathode electrode in order to increase the surface area of the cathode electrode. That is, it is preferable that a plurality of hollow insides of the cathode electrode are defined by the partitions. In this case, at least one through hole needs to be formed at each defined area.

[0044]

According to invention of claim 10 of the present application, in order to efficiently generate the hollow cathode discharge in the hollow inside of the cathode electrode, a height H of the hollow inside of the hollow-shaped cathode electrode is set in a range satisfying either of $H \leqq 5L(e)$ or $H \leqq 20X$. Here, $L(e)$ is an electron mean free path in respect to atom or molecular species (active species) of the smallest diameter among raw material gas species and electrically neutral atom or molecular species (active species) produced therefrom by decomposition, under the desired plasma generation conditions; and X is a thickness of a sheath layer generated under the desired plasma generation conditions. The height H of the hollow inside of the hollow-shaped cathode electrode is preferably set in a range also satisfying $X/5 \leqq$

H.

[0045]

[Embodiments of the Invention]

Hereinafter, the embodiment of the present invention will be described concretely referring to drawings and preferred embodiments.

Fig. 1 is a schematic view of a surface treatment apparatus 1 according to a first embodiment of the present invention. The apparatus 1 is shielded from the atmosphere, and a grounded casing 2 is divided into two chambers, a plasma generation chamber 3 and a substrate treatment chamber 4.

[0046]

A pair of plasma generation electrodes 5 and 6 are disposed in parallel vertically in the plasma generation chamber 3. The upper electrode (cathode electrode) 5 connected to a high frequency power supply P of the pair of electrodes 5 and 6, is attached to an upper wall 2a formed by an insulator of the casing 2, while the grounded lower electrode (anode electrode) 6 defines the plasma generation chamber 3 and the substrate treatment chamber 4. Here, the anode electrode 6 is attached to a peripheral wall 2b of the grounded casing 2, it is not limited to this, but it can be attached to any position of the casing 2.

[0047]

A round communication hole 7 is formed at the center

of the anode electrode 6, and the communication hole 7 composes a plasma nozzle 7 of the present invention. The plasma generation chamber 3 and the substrate treatment chamber 4 are connected each other through this plasma nozzle 7. Here, separately from the anode electrode 6, a partition plate to define the plasma generation chamber 3 and substrate treatment chamber 4 can be disposed and a plasma nozzle can be formed on the partition plate.

[0048]

Though cross section form of the plasma nozzle 7 is circular in this embodiment, it can also be, for example, rectangular, truncated cone shape increasing in its diameter from the plasma generation chamber 3 to the substrate treatment chamber 4, truncated prism shape, and further a shape whose diameter of upstream side approximate half decreases downwards and diameter of downstream side half increases downwards. And moreover, the plasma nozzle 7 may also be a slit form.

[0049]

An opening width W(A), that is, a diameter thereof W(A) of the plasma nozzle 7 is set in a range satisfying either of $W(A) \leqq 5L(e)$ or $W(A) \leqq 20X$. L(e) is an electron mean free path in respect to atom or molecular species (active species) of the smallest diameter among raw material gas species and electrically neutral atom or molecular species (active species) produced therefrom by decomposition, under the

desired plasma generation conditions, and X is a thickness of a sheath layer generated under the desired plasma generation conditions. Such range setting can make the plasma nozzle 7 the hollow anode discharge generation area. It is more preferable to set the opening width W further in a range satisfying $X/5 \leqq W(A)$.

[0050]

The upper cathode electrode 5 has a plurality of recesses 5a having circular cross section on the face thereof opposed to the anode electrode 6. The opening width W(C) of this recess 5a, namely the diameter W(C), is set in a range satisfying either of $W(C) \leqq 5L(e)$ or $W(C) \leqq 20X$. L(e) is an electron mean free path in respect to atom or molecular species (active species) of the smallest diameter among raw material gas species and electrically neutral atom or molecular species (active species) produced therefrom by decomposition, under the desired plasma generation conditions, and X is a thickness of a sheath layer generated under the desired plasma generation conditions. It is further preferable to set the opening width W further in a range satisfying also $X/5 \leqq W(C)$. Among the plasma generation conditions, if the gas pressure is in a range 10 to 1400 Pa, the diameter of the recess 5a is set in a range 1 to 100 mm, and more preferably it is 1 to 20 mm. By setting the diameter of the recess 5a in such range, the recess 5a can be made a hollow cathode discharge generation area.

[0051]

The approximate lower limit of a dimension T in the longitudinal direction (thickness direction) of the plasma nozzle 7 and a depth D of the recess 5a is X/50. The upper limit is decided by the apparatus dimensional restriction, namely, the thickness of the anode electrode 6, or the thickness of the cathode electrode 5. The length T of this plasma nozzle 7 and the depth D of the recess 5a is preferably 0.3 mm to 100 mm for the aforementioned gas pressure and diameter. Here, from the view point of effective generation of hollow cathode discharge, larger dimensions of the length T of the plasma nozzle 7 and the depth D of the recess 5a are advantageous and allow to generate a stronger plasma. Therefore, the substantial length T of the plasma nozzle 7 and the substantial depth D of the recess 5a may be increased by attaching a nozzle element to an opening edge of the plasma nozzle 7 or the recess 5a.

[0052]

Though the recess 5a has a circular cross section in this embodiment, it may be polygonal. The cross section area is not necessarily constant, and the cross section may vary in the axial direction and, for example, it may be a recess having a bottom face larger or smaller than the opening. Further, the recess 5a may be a groove structure having a rectangular form or a whorl form. In case it is a groove

structure having the rectangular form or the whorl form, the opening width W(C) of that recess 5a corresponds to a groove width (dimension between groove walls), and this groove width is set within the aforementioned range. Also, a partial relief may be formed on the inner wall face of the recess 5a. It is unnecessary to make a plurality of the recesses 5a have identical diameter or shape, and a plurality of recesses 5a having different dimensions and shape may be formed.

[0053]

In this embodiment, a gas inlet 8 is formed passing through the upper wall 2a of the casing 2 and the cathode electrode 5 and, in case of film formation treatment, mixed gas of raw material gas such as monosilane and carrier gas to accelerate the plasma generation, stabilize the plasma and transport raw material gas to a substrate S, is introduced in the plasma generation chamber 3 from this gas inlet 8. The shape of this gas inlet 8 is not limited to cylindrical form but it may be a rectangular tube.

[0054]

Also, a forming position of the gas inlet 8 is not limited to the aforementioned position. For instance, as shown in Fig. 2, it may formed at the opening position of the bottom section of the recess 5a, or formed at the opening position of the anode electrode 6 on the peripheral wall section. In addition, a plurality of the gas inlets 8 may be formed.

[0055]

The gas inlet 8 may introduce only carrier gas into the plasma generation chamber 3, and raw material gas may also be introduced inside the plasma generation chamber 3 or inside the film formation treatment chamber 4 through a different inlet installed separately.

[0056]

A substrate support table 9 is disposed in the film formation treatment chamber 4 at the position opposed to the plasma nozzle 7. In this embodiment, as the substrate support table 9 is grounded, the substrate S placed on the support table 9 is also grounded. The substrate support table 9 may be bias applied by a DC or AC-like way, or bias applied pulsatively without grounding. Besides, the substrate support table 9 has a built-in heater, for adjusting the temperature of the substrate S placed on an upper face of the substrate support table 9 to a temperature appropriate for vapor growth.

The film formation treatment chamber 4 is adjusted to have a chamber pressure lower than the plasma generation chamber 3 by not shown valve, pressure adjusting valve and vacuum pump.

[0057]

In case of film formation treatment by the surface treatment apparatus 1, when high frequency power is input from the high frequency source P to the cathode electrode 5,

discharge occurs between the electrodes 5 and 6 and plasma is generated in the plasma generation chamber 3. This plasma activates raw material gas and carrier gas introduced into the plasma generation chamber 3, and species contributing to the film formation are generated. At this moment, as the chamber pressure of the substrate treatment chamber 4 is adjusted lower than the plasma generation chamber 3, the plasma in the plasma generation chamber 3 flows out from the plasma nozzle 7 into the film formation treatment chamber 4. This plasma flow treats the surface of the substrate S in the treatment chamber 4 and form a thin film on the surface of the substrate S.

[0058]

At this moment, as the plurality of recesses 5a are formed on the cathode electrode 5 and the opening width W(C) of the recess 5a is set in the aforementioned range, the discharge changes from a normal glow discharge to the one including hollow cathode discharge according to the applied high frequency power. Hollow cathode discharge is generated at the recess 5a and new plasma is generated at the recess 5a. Therefore, plasma generated in the plasma generation chamber 3 increases in the density, active species contributing to the film formation increase, to speed up the surface treatment. Besides, the formation of the recess 5a on the cathode electrode 5 increases substantially the surface area of the cathode 5 in contact with plasma. This allow to bring the self bias

during the discharge generation further to the plus direction, accelerate raw material gas excitation, decomposition reaction in the vicinity of the grounded anode electrode 6, and speed up the surface treatment.

[0059]

Further, hollow anode discharge is generated at the plasma nozzle 7 by setting the opening width W(A) of the plasma nozzle 7 within the aforementioned range. As new plasma is generated at the plasma nozzle 7 by this hollow anode discharge, plasma introduced into the substrate treatment chamber 4 increases in its density. Moreover, the electron energy in the plasma generated in the plasma generation chamber 3 is reduced conveniently to an intensity sufficient for generating active species and insufficient for generating ions, when the plasma generated in the plasma generation chamber 3 passes through the plasma nozzle 7 which is hollow anode discharge generation area. Therefore, plasma introduced into the substrate treatment chamber 4 further increases species contributing to the film formation, increases in its density, and in the film formation speed remarkably. Still further, as the ion energy in the plasma also drops when it passes through the plasma nozzle 7 where the hollow anode discharge is being generated, the plasma introduced into the substrate treatment chamber 4 contains little ions which may damage the substrate by collision therewith, to enable a high quality film

formation.

[0060]

Though the anode electrode 6 is grounded in the aforementioned embodiment, the electrodes 5 and 6 may be bias applied respectively by a DC or AC power supply, or by a pulse power supply. Moreover, though, in the embodiment mentioned above, the anode electrode 6 defines the plasma generation chamber 3 and the substrate treatment chamber 4, a partition plate having a plasma nozzle can be disposed separately from the anode electrode 6, to define the plasma generation chamber 3 and the substrate treatment chamber 4.

Also, when other surface treatment such as ashing and etching is performed using above-mentioned apparatus, surface treatment can be conducted at a lower temperature and a higher speed than conventional apparatuses.

[0061]

Now the other embodiments of the present invention will be described concretely referring to drawings. In the following description, the reference numerals will be used for the same composition as the aforementioned first embodiment, and detailed description thereof will be omitted.

[0062]

Fig. 3 is a schematic view of a surface treatment apparatus 20 according to a second embodiment. The apparatus 20 is different from the aforementioned first embodiment in

that a magnet 10 is disposed on the inner wall face of the recess 5a formed on the cathode electrode 5 and on the inner wall face of the plasma nozzle 7, but otherwise, the composition is similar to the surface treatment apparatus 1 of the aforementioned first embodiment. It will be enough that the magnet 10 is disposed to impart magnetic field to the recess 5a or the plasma nozzle 7. For example, the magnet 10 may be embedded in the inner wall face, and also it may be embedded over the recess 5a in the cathode electrode 5 as shown in Fig. 4(a). Moreover, it may be disposed outside the cathode electrode 5 as shown in Fig. 4(b). As for the disposition of these magnets 10, it is preferable to attach the magnet 10 so as not to expose the magnet 10 directly to the plasma.

[0063]

The magnetic field of the magnet 10 is applied so that flux of the magnetic line becomes parallel to the respective axial direction of the recess 5a and the plasma nozzle 7. The intensity of the magnet is 1 to 2000 mT at the respective axial center of the recess 5a and the plasma nozzle 7, 2 to 2000 mT at the inner wall face and the vicinity thereof, and more preferably, 5 to 500 mT at the axial center, and 5 to 1000 mT at the inner wall face and the vicinity thereof.

[0064]

Such magnetic field formation at the recess 5a and plasma nozzle 7 allows electrons to remain for a long time in

the recess and plasma nozzle 7 by adjusting the electron orbit in the plasma generated there. Such the electron orbit adjustment makes the electron acting time to the raw material gas longer without elevating the electron energy (electron temperature), and the generation of active species is accelerated, improving the film formation speed.

[0065]

Besides, the magnetic field formation by disposing magnets 10 extends the dimensional tolerance of opening width W(C) or depth D of the recess 5a and opening width W(A) of the plasma nozzle 7 approximately by 30% more than the case without magnet disposition.

[0066]

Though the magnets 10 are disposed on all recesses 5a and plasma nozzles 7 in this embodiment, the magnets 10 may also be disposed only on the selected ones, in place of providing all of them with the magnet 10. Further, magnetic field may also be formed by electromagnet or other means. Magnetic field disposition including the magnet polarity and the intensity thereof are set arbitrarily so as to increase the plasma density.

[0067]

Fig. 5 is a schematic view of a surface treatment apparatus 21 according to a third embodiment. The apparatus 21 is different from the aforementioned first embodiment in

that the cathode electrode 11 has a hollow cylindrical form, but otherwise, the composition is similar to the surface treatment apparatus 1 of the aforementioned first embodiment.

[0068]

In the cathode electrode 11 which has the hollow cylindrical form, a plurality of through holes 11b having a circular cross section are formed at the portion opposed to the anode electrode 6, namely at a lower wall section 11a of the cathode electrode 11. In order to make this through hole 11b the hollow cathode discharge generation area, the opening width W(C) thereof, namely the diameter W(C) is set in a range satisfying either of $W(C) \leqq 5L(e)$ or $W(C) \leqq 20X$. L(e) is an electron mean free path in respect to atom or molecular species (active species) of the smallest diameter among raw material gas species and electrically neutral atom or molecular species (active species) produced therefrom by decomposition, under the desired plasma generation conditions, and X is a thickness of a sheath layer generated under the desired plasma generation conditions. It is preferable to set the opening width W(C) further in a range satisfying $X/5 \leqq W(C)$. Moreover, among the plasma generation conditions, if the gas pressure is in a range 10 to 1400 Pa, the diameter of the through hole 11b is set in a range of 1 to 100 mm, and more preferably it is 1 to 20 mm. By setting the diameter of the trough hole 11b in such range, hollow cathode discharge occurs in the trough hole 11b.

[0069]

The approximate lower limit of the length T of the trough hole 11b, namely the thickness T of the lower wall section 11a for this embodiment is X/50. The upper limit is decided by the apparatus dimensional restriction. The length T of this trough hole 11b is preferably 0.3 to 70 mm for the aforementioned gas pressure and diameter.

[0070]

Though the through hole 11b has a circular cross section in this embodiment, it may have a polygonal form. The cross section is not necessarily constant, and the cross section may change in the axial direction. Moreover, the trough hole 11b may be a slit structure having a rectangular cross section, or a slit structure having a whorl form. When such slit structure is adopted, the opening width W(C) of this through hole 11b corresponds to the slit width and this slit width is set within the aforementioned range. Also, a partial relief may be formed on the inner wall face of the through hole 11b. It is unnecessary to make a plurality of the through holes 11b identical each other in dimensions or shape, and a plurality of through holes 11b having different dimensions and shape may be formed.

[0071]

In this embodiment, in order to make the hollow inside of the cathode electrode 11 the hollow cathode discharge

generation area, a height H of the hollow inside of the cathode electrode 11 is set in a range satisfying either of $H \leqq 5L(e)$ or $H \leqq 20X$. L(e) is an electron mean free path in respect to atom or molecular species (active species) of the smallest diameter among raw material gas species and electrically neutral atom or molecular species (active species) produced therefrom by decomposition, under the desired plasma generation conditions, and X is a thickness of a sheath layer generated under the desired plasma generation conditions. In addition, it is preferable to set the height H of the hollow inside in a range satisfying $X/5 \leqq H$. Among the plasma generation conditions, if the gas pressure is in a range 10 to 1400 Pa, and the dimensions of the through hole 11b is in the range mentioned above, the height H of the hollow inside is preferably set to be 0.2 to 200 mm.

[0072]

A cylindrical gas inlet 11d is formed at the center of the upper wall section 11c of the cathode electrode 11 and, mixed gas of raw material gas such as monosilane and carrier gas to accelerate the plasma generation, stabilize the plasma and transport raw material gas to the substrate S, is introduced into the hollow inside of the cathode electrode 11 from this gas inlet 11d. The shape of this gas inlet 11d is not limited to cylindrical form but it may be a rectangular tube. In addition, the formation position of the gas inlet 11d is not

limited to the center of the upper wall section 11c, but it may be formed at any position.

[0073]

The mixed gas introduced to the hollow inside of the cathode electrode 11 from such gas inlet 11d is introduced in shower form into the plasma generation chamber 3 from the through holes 11b. Thus, the mixed gas can be introduced in the plasma generation chamber 3 with an uniform density and pressure, by retaining once the mixed gas inside the cathode electrode 11 and then introducing into the plasma generation chamber 3 in shower form through the through holes 11b.

[0074]

Only carrier gas may introduced into the cathode electrode 11 hollow inside, and raw material gas may be introduced inside the plasma generation chamber 3 or inside the film formation treatment chamber 4 through a different inlet installed separately.

[0075]

When a high frequency power is input from the high frequency power source P to the cathode electrode 11, discharge occurs between the electrodes 11 and 6 and plasma is generated in the plasma generation chamber 3. The discharge changes from a normal glow discharge to the one including hollow cathode discharge according to the applied high frequency power. As for the cathode electrode 11, hollow cathode discharge is

generated at the through hole 11b and new plasma is generated at the through hole 11b and hollow cathode discharge is also generated in the hollow inside of the cathode electrode 11 and new plasma is generated. Therefore, plasma generated in the plasma generation chamber 3 increases in the density, and the active species contributing to the film formation increase so as to speed up the surface treatment. Further, as the cathode electrode 11 is a hollow element and the through holes 11b are provided so that plasma is generated in the through holes 11b and the hollow inside, the surface area of the cathode electrode 11 substantially in contact with plasma increases further than the case of the first embodiment mentioned above. This allow to bring the self bias during the discharge generation further to the plus direction further, accelerate raw material gas excitation, decomposition reaction in the vicinity of the grounded anode electrode 6, and speed up the surface treatment.

<Experiment 1>

In a surface treatment apparatus 21 according to the third embodiment, the diameter of the through hole 11b of the cathode electrode 11 was set to 2 to 20 mm, the length dimension T of the through hole 11b 2 to 8 mm, the height H of the hollow inside 2 to 20 mm, the hydrogen gas pressure 133 Pa and an RF power of 3.56 MHz in frequency was applied by 0.02 W/cm^2. As a result, hollow anode discharge was generated at the plasma nozzle 7 and hollow cathode discharge was generated in the

through holes 11b of the cathode electrode 11 and in the hollow inside thereof.

[0076]

At this time, even the lowest value of the cathode electrode 11 self bias was -9 V. On the contrary, for the ordinary regular discharge type where the diameter of the through hole 11b of the cathode electrode 11 is 1 mm, and hollow cathode discharge is not generated in the through hole 11b and in the hollow inside, the cathode electrode self bias is -30 V for the same gas pressure and RF power, and the self bias is -74V for the ordinary parallel flat plate type. This teaches that, in the surface treatment apparatus 21 of the aforementioned embodiment the self bias of the cathode electrode 11 shifted extremely toward the plus side. It is also possible to change the polarity to shift the self bias toward the positive potential depending on conditions.

[0077]

Besides, in the aforementioned conditions, when the length dimension T of the through hole 11b of the cathode electrode 11 was set to 9 mm, hollow cathode discharge was not generated in the through hole 11b and, hollow cathode discharge was not generated in the hollow inside of the cathode electrode 11, neither. When the RF power was increased, keeping the length dimension T of the through hole 11b at 9 mm, hollow cathode discharge was generated in the through hole 11b of the

cathode electrode 11 and in the hollow inside thereof, at 0.05 W/cm^2.

[0078]

Next, when the diameter of the through hole 11b of the cathode electrode 11 was set to 5 mm, and the height H of the hollow inside of the cathode electrode 11 to 2 mm, hollow cathode discharge was not generated in the hollow inside when the RF power is equal or inferior to 0.02 W/cm^2, but self bias of the cathode electrode 11 was -6 V, shifted extremely toward the plus side. When the height H is set to 9 mm, hollow cathode discharge was not generated in the hollow inside when the RF power is equal or inferior to 0.05 W/cm^2, but in this case also, self bias of the cathode electrode 11 was -9 V, a higher voltage compared to the aforementioned regular discharge type or normal parallel flat type.

<Experiment 2>

Using the surface treatment apparatus 21 and monosilane gas (SiH_4) as raw material gas by the flow rate of 7 cm^3/min and introducing hydrogen gas as carrier gas by the flow rate of 105 cm^3/min, setting the pressure of the film formation chamber at 29 Pa, the substrate temperature 150 to 260 ℃ and applying a high frequency power of 13.56 MHz, 0.1 W/cm^2, the film formation treatment was performed onto a white glass plate substrate. As a result, a fine crystalline thin film was formed on the substrate surface even when the substrate

temperature was as low as 150 ℃. In this temperature range, the fine crystalline thin film formation maximum speed was 40 Å/sec, allowing to realize a high speed film formation that was not achieved by the prior art. Moreover, an extremely fast film formation as 150 Å/sec can be realized by optimizing the film forming conditions and by setting the substrate temperature to 300 ℃, and in such a fast film formation, the thin film was fine crystallized, providing a thin film that can function sufficiently as a solar cell. It goes without saying that film can be formed still faster, if an amorphous thin film is to be formed.

[0079]

Such improvement of film formation speed can be explained by, first, the realization of high density plasma by hollow anode discharge at the plasma nozzle 7 and hollow cathode discharge at the through hole 11b of the cathode electrode 11 and the hollow inside thereof. Further, the increase of the surface area of the cathode electrode 11 in contact with plasma allows to bring its self-bias to the plus side and plasma is generated also in the vicinity of the anode electrode, permitting to lead plasma to the substrate surface effectively through the plasma nozzle 7 to the substrate treatment chamber 4. Besides, as the control of the self bias allows to control the plasma space potential at the same time, the crystallization at high speed film formation is believed

to be realized by setting this plasma space potential conveniently and imparting a convenient ion impact according to the film formation speed.

[0080]

The substrate treatment apparatus 21 mentioned above could perform the surface treatment at a lower temperature and faster than before, when it is applied to the surface treatment other than film formation, such as ashing and etching.

[0081]

Fig. 6 is a schematic view of a substrate treatment apparatus 22 according to a fourth embodiment of the present invention. The composition of the apparatus 22 is identical to the substrate treatment apparatus 21 of the aforementioned third embodiment except that magnets 10 are arranged on the inner wall face of the through holes 11b formed across the hollow-shaped cathode electrode 11 and on the plasma nozzle 7 inner wall face.

[0082]

The magnetic field of the magnet 10 is applied such that the magnetic line of flux is directed parallel to the respective axial directions of the through hole 11b and the plasma nozzle 7. The magnet intensity is preferably 1 to 2000 mT at the respective axial center of the through hole 11b and plasma nozzle 7, 2 to 2000 mT at the inner wall face and in the vicinity thereof, and more preferably 5 to 500 mT at the axial center,

and 5 to 1000 mT at the inner wall face and in the vicinity thereof.

[0083]

Such magnetic field formation at the through hole 11b and plasma nozzle 7 allows electrons to remain for a long time in the through hole 11b and plasma nozzle 7 by adjusting the orbit of electrons in the plasma generated therein. Such electron obit adjustment accelerates the generation of active species and improves the film formation speed, as the electron acting time to the raw material gas is extended without increasing the electron energy (electron temperature).

[0084]

Besides, the magnetic field formation by disposing magnets 10 extends the dimensional tolerance of the opening width W(C) and the length T of the through hole 11b and the opening width W(A) of the plasma nozzle 7 approximately by 30% more than the case without magnet disposition.

[0085]

Though all of through holes 11b and plasma nozzles 7 are provided with the magnet 10 in this embodiment, the magnet 10 may be disposed only on the selected ones, in place of providing all of them with the magnet 10. The magnetic field may well be formed by electromagnet or other means. Moreover, the magnet 10 may be embedded in the inner wall face of the through holes 11b and plasma nozzles 7. In addition, it may

also be embedded in the upper wall section 11c of the cathode electrode 11, which is a hollow element, as shown in Fig. 7(a), or disposed outside the cathode electrode 11 and above the upper wall section 11c as shown in Fig. 7(b). Magnetic field disposition including the polarity of the magnet 10 and the intensity thereof are set arbitrarily in a way to increase the plasma density.

[0086]

It is also possible to arrange the magnet so that hollow cathode discharge in the hollow inside becomes more dense. For example, as shown in Fig. 8(a), they may be arranged in the upper and lower wall sections 11c and 11a of the cathode electrode 11 and outside the peripheral wall section of the cathode electrode 11. Also, as shown in Fig. 8(b), they may be arranged inside the upper wall section 11c of the cathode electrode 11 and outside the lower wall section 11a and the peripheral wall section. In this case, the disposition of the magnet and the intensity of the magnetic field are arbitrarily set so as to make hollow cathode discharge at the hollow inside becomes more dense by embedding the magnet 10 inside the cathode electrode 11 or disposing the magnet 10 outside the cathode electrode 11, or by their combination.

<Experiment 3>

Using the surface treatment apparatus 22 according to the fourth embodiment, under the conditions as the Experiment

2 of the aforementioned third embodiment, namely, introducing monosilane gas (SiH_4) at the flow rate of 7 cm^3/min and hydrogen gas at the flow rate of 105 cm^3/min, setting the pressure of the film formation chamber at 29 Pa, the substrate temperature 150 to 260 ℃ and applying a high frequency power of 13.56 MHz, 0.1 W/cm^2, the film formation treatment was performed onto a white glass plate substrate. As a result, a thin film was formed at 70 Å/sec, allowing to realize a high speed film formation 75 % higher than the aforementioned third embodiment, and in such a fast film formation, the thin film was fine crystallized, providing a thin film that can function sufficiently as a solar cell.

[0087]

Now, a modification for increasing the density of plasma generated by hollow cathode discharge in the through hole 11b of the cathode electrode 11 or its hollow inside is shown in Fig. 9.

First, from the view point of effective generation of hollow cathode discharge in the through hole 11b, it is preferable to enlarge the length T of the through hole 11b, to generate stronger plasma. However, the thickness of the lower wall section 11a of the cathode electrode 11 is preferably minimum for resisting the gas pressure introduced into the hollow inside and the applied electricity, from the viewpoint of material cost.

[0088]

Therefore, to increase the length T of the through hole 11b, it is preferable to attach a nozzle element 12 at the periphery of the through hole 11b. This nozzle element 12 may protrude from the through hole 11b to the plasma generation chamber 3 side, or protrude into the hollow inside. It may also protrude to both sides. The same nozzle element 12 may also be composed of magnet 10 as shown in Fig. 9.

[0089]

Though all nozzle elements 12 shown in Fig. 9 are disposed aligning its center line with the line of the through hole 11b, the centrer line of the nozzle element 12 and the axial line of the through hole 11b may make a certain angle, namely, the nozzle element 12 may be disposed on the slant. Though the nozzle element 12 shown in Fig. 9 is a cylinder having a constant cross section, the shape is not limited to this, but it may be a cylinder having a shape gradually increasing or reducing its cross section. Moreover, tubular nozzle elements can be disposed in spiral. Such variation of the nozzle element can also be applied to the nozzle element attached to the aforementioned plasma nozzle or recess.

[0090]

Moreover, in order to increase the surface area of the cathode electrode 11 in contact with plasma, the hollow inside of the cathode electrode 11 may by partitioned by a partition

wall 11e extending in its height direction. As the surface area can be adjusted freely, the self-bias of the cathode electrode 11 can be controlled freely. In this case, it is preferable to provide a gas inlet to each partitioned space.

[0091]

Though Fig. 9 illustrates shapes of the plurality of through holes 11b, it is not limited to the illustrated embodiment where all through holes 11b have different shapes. All through holes 11b may have the same shape, or several kinds of through holes 11b may coexist. Also, the length dimension of the nozzle element 12 may be identical for all through holes 11b or may vary conveniently, to uniform the intensity of plasma attaining the substrate surface all over the substrate surface area. Besides, the position and the number of partition wall formation are not limited to the Fig. 9, but they can be designed freely according to the plasma intensity required for the surface treatment.

[0092]

Also, it is known that, as a factor affecting the plasma intensity, the elevation of high frequency excitation power supply frequency accelerates the crystallization. So, an experiment is made to vary the frequency.

<Experiment 4>

In the experiments 1 to 3 mentioned above, a high frequency power excitation power supply frequency was set to

13.56 MHz; it was changed to 105 MHz., and the film formation treatment was performed under the same conditions, and as a result, the thin film was crystallized even at the film formation speed of 260 Å/sec by an effect of the high frequency in addition to the effects in the respective experiments. When the film formation speed was 240 Å/sec, the crystallized film that can function sufficiently as a solar cell was obtained.

[0093]

Fig. 10 is a schematic view of a surface treatment apparatus 23 according to a fifth embodiment of the present invention. The apparatus 23 is different from the aforementioned third embodiment in that the inner wall face of the hollow inside is composed of an insulator so that hollow cathode discharge is not generated in the hollow inside of the cathode electrode 11', but otherwise, the composition is similar to the surface treatment apparatus 21 of the aforementioned third embodiment.

[0094]

However, the electrode may partially be exposed on the inner face of the lower wall section 11a of the cathode electrode 11', and in this case, plasma generated in the plasma generation chamber 3 penetrates into the hollow inside through the through holes 11b to creep over this exposed electrode face. Thereby, the surface area of the cathode electrode 11' substantially in contact with plasma increases, allowing to

increase the self bias.

[0095]

In order to prevent hollow cathode discharge from being generated in the hollow inside of the cathode electrode 11', in addition to the aforementioned composition of the inner wall surface with an insulator, the height H of the hollow inside may be increased, however, it is more reliable to compose the inner wall surface with an insulator, because this height H may vary depending on RF power or gas pressure.

[0096]

Thus, plasma can be generated with the intensity corresponding to the application, because not only the plasma generation site can be controlled, but also the surface area of the cathode electrode 11' in contact with plasma can be adjusted, and the self bias can be controlled.

<Experiment 5>

The film formation treatment was performed using the aforementioned surface treatment apparatus 23, under the conditions as the aforementioned Experiment 2, and hollow cathode discharge was generated in the through holes 11b, hollow anode discharge is generated in the plasma nozzle 7, and plasma density increased, allowing to form fine crystalline thin film was at a high speed. Besides, the obtained crystallized film could function sufficiently as a solar cell.

[0097]

Fig. 11 is a schematic view of a surface treatment apparatus 24 according to a sixth embodiment of the present invention. The surface treatment apparatus 24 corresponds to the surface treatment apparatus 23 of the aforementioned fifth embodiment wherein magnets 10 are arranged on the inner wall face of the through hole 11b of the cathode electrode 11b and on the inner wall face of the plasma nozzle 7.

<Experiment 6>

The film formation was performed using the aforementioned surface treatment apparatus 24 of the sixth embodiment, under the conditions same as the aforementioned Experiment 2, resulting in the improvement of film formation speed or battery efficiency by 10% or more compared to the aforementioned Experiment 5.

[0098]

As a modification of the aforementioned hollow-shaped cathode electrode 11, for example, the space between the lower wall section 41a including a plurality of through holes 41b and the upper wall section 41c may be partitioned into a plurality of stages in a vertical direction by one or more partition walls 41e including one or more through holes 41d, like as the cathode electrode 41 which is a hollow element shown in Fig. 12(a). Alternatively, a plurality of hollow-shaped electrode members 51a can be communicated in a plurality of stages in a vertical direction by a communication opening 51b

like as the hollow-shaped cathode electrode 51 shown in Fig. 12(b).

[0099]

Fig. 13 is a schematic view of a surface treatment apparatus 25 according to a seventh embodiment of the present invention. In this surface treatment apparatus 25, the inside of the casing 2 is also divided into two chambers, the plasma generation chamber 3 and the substrate treatment chamber 4. The cathode electrode 5 and an anode electrode 6' are disposed in the plasma generation chamber 3 and the anode electrode 6' divides the plasma generation chamber 3 and the substrate treatment chamber 4. A circular plasma nozzle 7' is formed at the center of the anode electrode 6', and this plasma nozzle 7' connects the plasma generation chamber 3 and substrate treatment chamber 4.

[0100]

For the cathode electrode 5, a plurality of recesses 5a having circular cross section are disposed on the face of the cathode electrode 5 opposed to the anode electrode 6'. The opening width W(c) of this recess 5a is set in a range satisfying either of W(c) 5L(e) or W(c) $\leqq$ 20X. It is more preferable to set the opening width W(c) in a range satisfying X/5 $\leqq$ W(c). Hollow cathode discharge is generated at the recess 5a by setting the diameter of the recess 5a in such range.

[0101]

The aforementioned composition of this embodiment is similar to the first embodiment mentioned above, but it is different from the surface treatment apparatus 1 of the aforementioned first embodiment in that hollow discharge is not generated at the plasma nozzle 7', because the opening width W(A) of the plasma nozzle 7' formed at the anode electrode 6' is large or the length (thickness) T is small.

[0102]

As hollow discharge is not generated at the plasma nozzle 7' in this embodiment, the surface treatment speed and quality are somewhat inferior to the aforementioned first embodiment, but its treatment speed and treatment quality is improved, compared to the conventional surface treatment apparatus, because hollow cathode discharge is generated at the recess 5a of cathode electrode 5.

[0103]

Fig. 14 is a schematic view of a surface treatment apparatus 26 according to an eighth embodiment of the present invention. In this surface treatment apparatus 26 also, the inside of the casing 2 is divided into two chambers, the plasma generation chamber 3 and the substrate treatment chamber 4. A cathode electrode 5" and an anode electrode 6" are disposed in the plasma generation chamber 3 and the power applied cathode electrode 5" divides the plasma generation chamber 3 and the substrate treatment chamber 4. A circular plasma nozzle 7"

is formed at the center of the cathode electrode 5", and this plasma nozzle 7" connects the plasma generation chamber 3 and the substrate treatment chamber 4.

[0104]

As the opening width W of the plasma nozzle 7" is set in a range satisfying either of $W \leqq 5L(e)$ or $W \leqq 20X$, hollow cathode discharge is generated at the plasma nozzle 7". In other words, the plasma nozzle 7" of this embodiment corresponds to the hollow discharge area of the invention according to claim 1 of the present invention and at the same time, corresponds to the hollow cathode discharge area of the invention according to claim 2 of the present invention.

[0105]

Though the plasma generation chamber 3 is disposed above the surface treatment apparatus and the substrate treatment chamber 4 is disposed thereunder in any of the aforementioned embodiment, contrarily to these embodiments, the apparatus may be so composed to flow plasma from under to upward by arranging the plasma generation chamber 3 under, and the substrate treatment chamber 4 thereabove. Further, the casing of the surface treatment apparatus may be divided into right and left chambers, and the plasma generation chamber and the substrate treatment chamber may be disposed horizontally, to compose an apparatus in which plasma flows in the traversal direction. In any case, the substrate can by disposed in opposition to

the plasma nozzle and orthogonal to the plasma flow direction or the substrate can be disposed parallel to the plasma flow direction. The plasma generation means is also not limited to a pair of plasma generation electrodes, but includes plasma generation means such as discharge including electrodes of three poles or more, microwave discharge, capacitance coupling type discharge, inductive coupling type discharge, PIG discharge, electron beam excitation discharge.

[0106]

As shown in Fig. 15, another electrode 13 can be disposed in the vicinity of anode side and/or opposite side of the cathode electrode 5 where hollow cathode discharge is generated. The another electrode 13 has multiple small holes 13a formed thereon, having an opening width smaller than the opening width W(C) of the recess 5a formed at the cathode 5. Otherwise, the another electrode 13 may be mesh shaped. Even in case of cathode electrode having a through hole where hollow cathode discharge is generated, similarly, another electrode 13 provided with multiple small holes smaller than the opening width W(C) of the through hole may be disposed.

[0107]

The another electrode 13 is biased to an arbitrary voltage including floating state, and it is particularly preferable that it is set to a voltage value between the grounded anode electrode 6 and the maximum value of the plasma

space potential, or it is set to a voltage value between the voltage of the cathode electrode 5 where hollow cathode discharge is generated and the maximum value of the plasma space potential.

[0108]

Moreover, much electrons will be defined in the hollow cathode discharge area and an ultra high density hollow cathode discharge, which is a discharge of much more electric current, becomes possible by forming the small holes 13a formed on the another electrode 13 at a position corresponding to the recess 5a or through hole of the cathode electrode 5 as shown in Fig. 15.

[0109]

Alternatively, electrons can be entrapped effectively in a through hole 11b", that is a hollow cathode discharge area, by forming the through hole 11b", whose area at an opening portion is sufficiently smaller than other portions, at the cathode electrode 11" as shown in Fig. 16. Meanwhile, also in the recess formed in the cathode electrode, electrons can be entrapped in the hollow cathode discharge area in the recess if an area at an opening portion of the recess is sufficiently smaller than the other portions.

[0110]

Though, a high frequency power by a high frequency power supply P is input to the plasma generation electrode, DC voltage

may be applied by a DC power supply. Or, bias may be applied respectively by a DC or AC power supply, or by a pulse power supply.

Moreover, it is also possible to compose in the triode type by installing mesh shaped electrodes between the substrate S placed in the surface treatment chamber 4 and the plasma nozzle 7, and to apply various bias.

[0111]

Though the inside of the casing 2 of the surface treatment apparatus is vertically divided into two chambers, the plasma generation chamber 3 above and the substrate treatment chamber 4 under, by an anode electrode 6 in every embodiment mentioned above, the present invention is not limited to such apparatus.

[0112]

Fig. 17 to Fig. 22 are horizontal cross sections of a surface treatment apparatus according to other embodiments of the present invention.

In a surface treatment apparatus 31 shown in Fig. 17, a casing 32 is composed of a bottomed cylinder, and the peripheral wall inner surface is used as the substrate support table 9. In this case, a cathode electrode 35 composed of small diameter cylinder and an anode electrode 36 composed of a cylinder whose diameter is larger than the cathode electrode 35 are disposed in the casing 32 aligning their central axes.

[0113]

A plurality of plasma nozzles 37 having a predetermined shape and disposition are formed at the anode electrode 36, the area between the anode electrode 36 and the casing 32 composes a substrate treatment chamber 34 of the present invention, and the area between the cathode electrode 35 and the anode electrode 36 composes a plasma generation chamber 33 of the present invention. Further, a plurality of recesses 35a parallel to the axial direction are formed on the peripheral wall face of the cathode electrode 35 with a predetermined phase difference. Moreover, When the cathode electrode 35 is a hollow element, a through hole may be formed in place of the recess 35a, and its hollow inside may be supplied with carrier gas and raw material gas.

[0114]

Alternatively, as shown in Fig. 18, the maximum diameter cylinder can be set as cathode electrode 35 and the anode electrode 36 made of a cylinder may be disposed therein aligning their axes, and further a smallest diameter cylinder 39 may be disposed at the center thereof. In this case, the outer circumferential surface of the central cylinder 39 composes a support table for the substrate W. A plurality of the recesses 35a parallel to the axial direction are formed on the inner circumference surface of the cathode electrode 35 with a predetermined phase difference. A plurality of the plasma nozzles 37 having a predetermined shape and disposition are

formed at the anode electrode 36. Further, the casing may be disposed further outside of the cathode electrode 35.

[0115]

In the embodiments shown in Figs. 17 and 18 also, hollow anode discharge is generated at the plasma nozzle 37 by setting the opening width of the nozzle within the range prescribed by the present invention. Also, hollow cathode discharge is generated at the recess 35a, by setting the opening width of the recess 35a within the range prescribed by the present invention.

[0116]

Such apparatus wherein the anode electrode 35 and cathode electrode 36 are made of cylinder, is useful for applying surface treatment to the cylindrical substrate such as photosensitive dram. Alternatively, it is preferable, in roll-to-roll continuous film formation, etching or other surface treatment is applied to a substrate made of band shaped film member, taking profit of the curbed surface of a part of the cylinder because space required for the apparatus can be reduced.

[0117]

Respective plasma generation electrode may be spherical and have a cross section form as shown in the aforementioned Figs. 17 and 18. Alternatively, respective plasma generation electrodes 35 and 36 may be formed so that its cross section

is a part of curbed surface such as semicircular cylinder or hemisphere as shown in Figs. 19 and 20. Thus, by making the plasma generation electrode spherical, hemispherical or partially curbed surface, an uniform surface treatment can be applied to special form substrates such as spherical semiconductor.

[0118]

Moreover, as shown in Figs. 21 and 22, plasma generation electrodes 35 and 36 may be a cylinder having a square cross section. Or they may be have a cylinder shape with polygonal cross section or polyhedron shape. By making the plasma generation electrodes 35 and 36 prism shaped, the apparatus space can be reduced.

[Brief Description of the Drawings]

[Fig. 1]

A schematic view of a surface treatment apparatus according to a first embodiment of the present invention.

[Fig. 2]

A schematic view showing a disposition example of a gas inlet according to a modification of the apparatus.

[Fig. 3]

A schematic view of a surface treatment apparatus according to a second embodiment of the present invention.

[Fig. 4]

Schematic views showing other disposition examples of

a magnet in respect to a cathode electrode.

[Fig. 5]

A schematic view of a surface treatment apparatus according to a third embodiment of the present invention.

[Fig. 6]

A schematic view of a surface treatment apparatus according to a fourth embodiment of the present invention.

[Fig. 7]

Schematic views showing other disposition examples of the magnet in respect to a hollow cathode electrode.

[Fig. 8]

Schematic views showing still other disposition examples of the magnet in respect to the hollow cathode electrode.

[Fig. 9]

A schematic view of a cathode electrode according to a modification of the apparatus of the third and fourth embodiments.

[Fig. 10]

A schematic view of a surface treatment apparatus according to a fifth embodiment of the present invention.

[Fig.11]

A schematic view of a surface treatment apparatus according to a sixth embodiment of the present invention.

[Fig. 12]

Schematic views showing other embodiments of the hollow cathode electrode.

[Fig. 13]

A schematic view of a surface treatment apparatus according to a seventh embodiment of the present invention.

[Fig. 14]

A schematic view of a surface treatment apparatus according to an eighth embodiment of the present invention.

[Fig. 15]

A schematic view of a cathode electrode portion which can be applied to a surface treatment apparatus according to another embodiment of the present invention.

[Fig. 16]

A schematic view of another cathode electrode portion which can be applied to a surface treatment apparatus according to still another embodiment of the present invention.

[Fig. 17]

A horizontal schematic sectional view of a surface treatment apparatus according to still another embodiment of the present invention.

[Fig. 18]

A horizontal schematic sectional view of a surface treatment apparatus according to still another embodiment of the present invention.

[Fig. 19]

A horizontal schematic sectional view of a surface treatment apparatus according to still another embodiment of the present invention.

[Fig. 20]

A horizontal schematic sectional view of a surface treatment apparatus according to still another embodiment of the present invention.

[Fig. 21]

A horizontal schematic sectional view of a surface treatment apparatus according to still another embodiment of the present invention.

[Fig. 22]

A horizontal schematic sectional view of a surface treatment apparatus according to still another embodiment of the present invention.

[Reference Numerals]

1, 20, 21, 22, 23, 24, 25, 26	Surface treatment apparatus
2	Casing
2a	Upper wall
2b	Peripheral wall
3	Plasma generation chamber
4	Substrate treatment chamber
5, 5"	Cathode electrode
5a	Recess

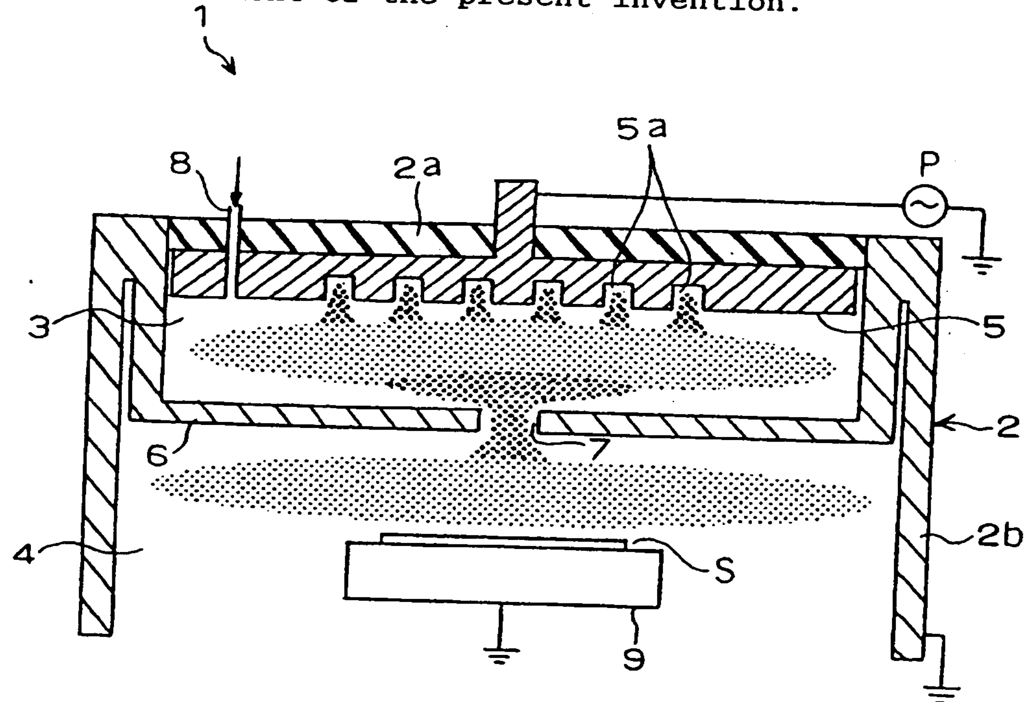
6, 6', 6"	Anode electrode
7, 7', 7"	Plasma nozzle
8	Gas inlet
9	Substrate support table
10	Magnet
11, 11', 11"	Cathode electrode
11a	Lower wall section
11b	Through hole
11c	Upper wall section
11d	Gas inlet
11e	Partition wall
12	Nozzle element
13	Another electrode
13a	Small hole
32	Casing
33	Plasma generation chamber
34	Substrate treatment chamber
35	Cathode electrode
35a	Recess
36	Anode electrode
37	Plasma nozzle
39	Substrate support table
41	Cathode electrode
41a	Lower wall section
41b	Through hole

41c	Upper wall section
41d	Through hole
41e	Partition wall
51	Cathode electrode
51a	Hollow-shaped electrode member
51b	Communication opening
S	Substrate
P	High frequency power supply

【書類名】 図面 [DOCUMENT NAME] Drawings

【図１】 [Fig. 1]

本発明の第１実施例である表面処理装置の概略図
A schematic view of a surface treatment apparatus according to a first embodiment of the present invention.



1	表面処理装置	6	アノード電極
2	ケーシング	7	プラズマ吹出口
2 a	上壁	8	ガス供給口
2 b	周壁	9	基板支持台
3	プラズマ発生室	S	基板
4	基板処理室	P	高周波電源
5	カソード電極		
5 a	凹部		

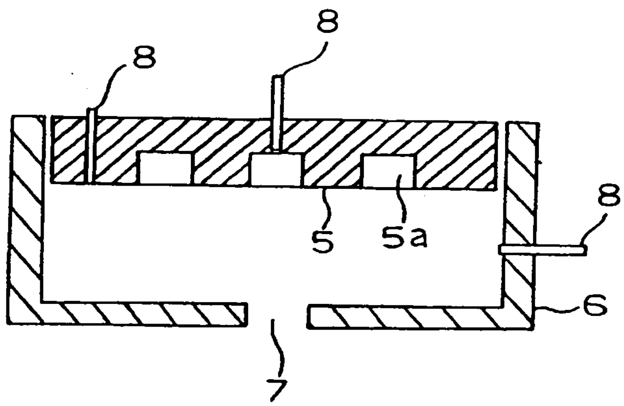
1	Surface treatment apparatus	6	Anode electrode
2	Casing	7	Plasma nozzle
2a	Upper wall	8	Gas inlet
2b	Peripheral wall	9	Substrate support table
3	Plasma generation chamber	S	Substrate
4	Substrate treatment chamber	P	High frequency power supply
5	Cathode electrode		
5a	Recess		

【図２】

本発明の第１実施例である表面処理装置の変形例によるプラズマ発生電極の概略図

[Fig. 2]

A schematic view of a plasma generation electrode according to a modification of the apparatus of the first embodiment of the present invention.



5　カソード電極
5a　凹部
6　アノード電極
7　プラズマ吹出口
8　ガス供給口

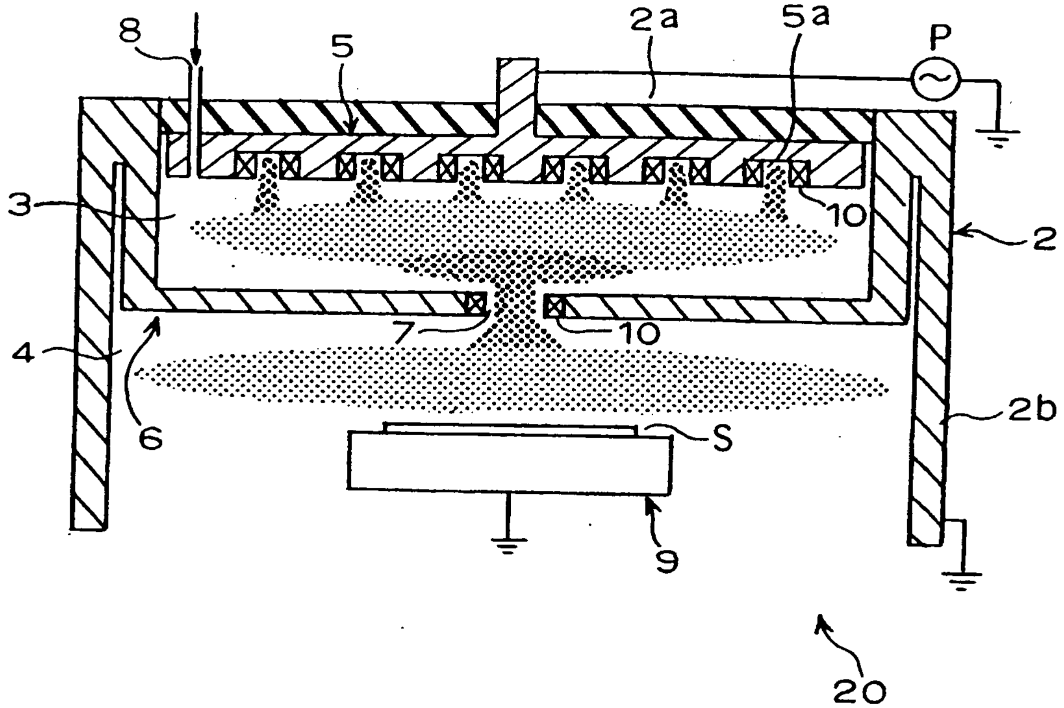
5 Cathode electrode
5a Recess
6 Anode electrode
7 Plasma nozzle
8 Gas inlet

【図３】

第２実施例である表面処理装置の概略図

[Fig. 3]

A schematic view of a surface treatment apparatus according to a second embodiment.



２０	表面処理装置	6	アノード電極
２	ケーシング	7	プラズマ吹出口
２ａ	上壁	8	ガス供給口
２ｂ	周壁	9	基板支持台
３	プラズマ発生室	１０	磁石
４	基板処理室	S	基板
５	カソード電極	P	高周波電源
５ａ	凹部		

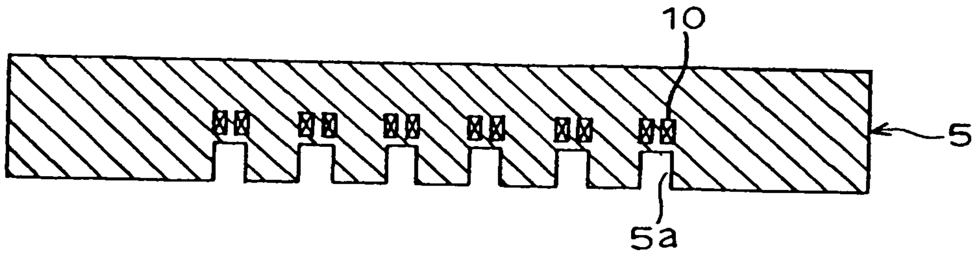
20	Surface treatment apparatus	6	Anode electrode
2	Casing	7	Plasma nozzle
2a	Upper wall	8	Gas inlet
2b	Peripheral wall	9	Substrate support table
3	Plasma generation chamber	10	Magnet
4	Substrate treatment chamber	S	Substrate
5	Cathode electrode	P	High frequency power supply
5a	Recess		

【図４】

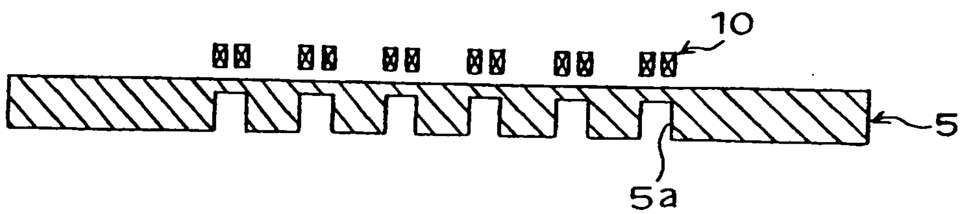
第３実施例である表面処理装置の概略図

[Fig. 4]
Schematic views of surface treatment apparatuses according to a third embodiment.

(a)



(b)

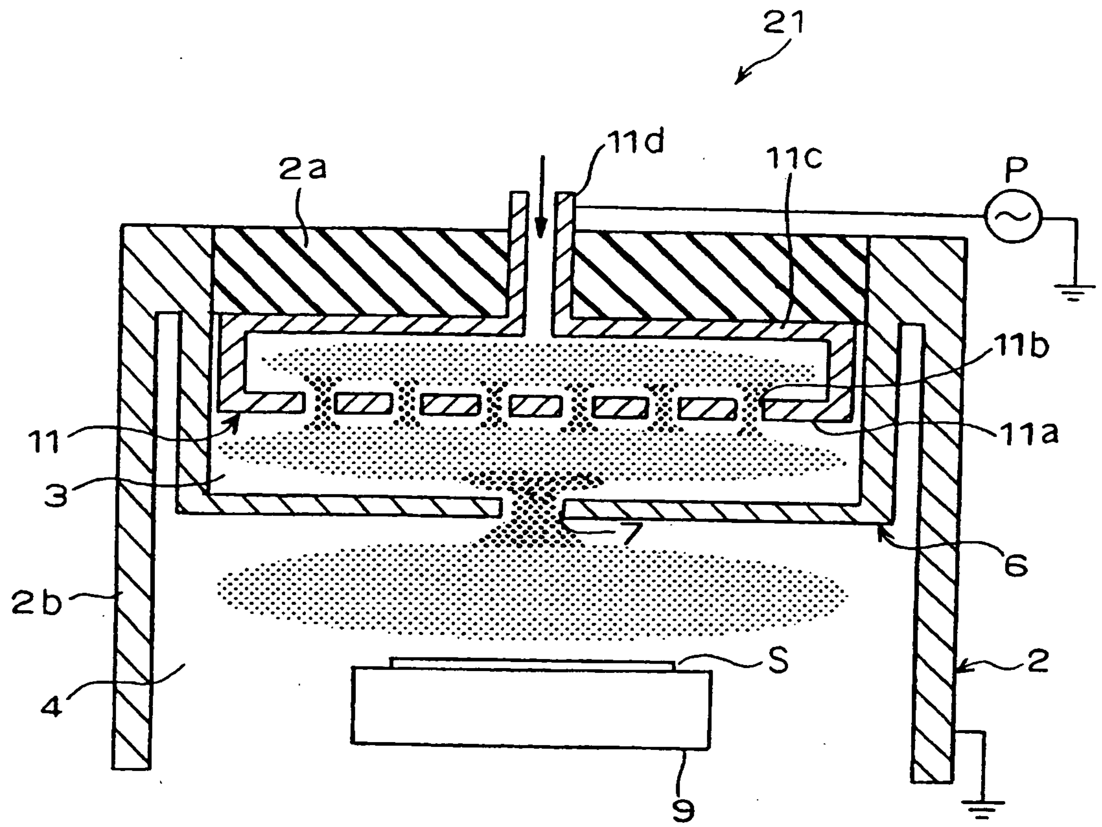


５　カソード電極
５ａ　凹部
１０　磁石

5　Cathode electrode
5a　Recess
10　Magnet

【図５】　[Fig. 5]

第４実施例である表面処理装置の概略図
A schematic view of a surface treatment apparatus according to a fourth embodiment.



２１	表面処理装置	１１	カソード電極
２	ケーシング	１１ａ	下壁部
２ａ	上壁	１１ｂ	貫通孔
２ｂ	周壁	１１ｃ	上壁部
３	プラズマ発生室	１１ｄ	ガス供給口
４	基板処理室	Ｓ	基板
６	アノード電極	Ｐ	高周波電源
７	プラズマ吹出口		

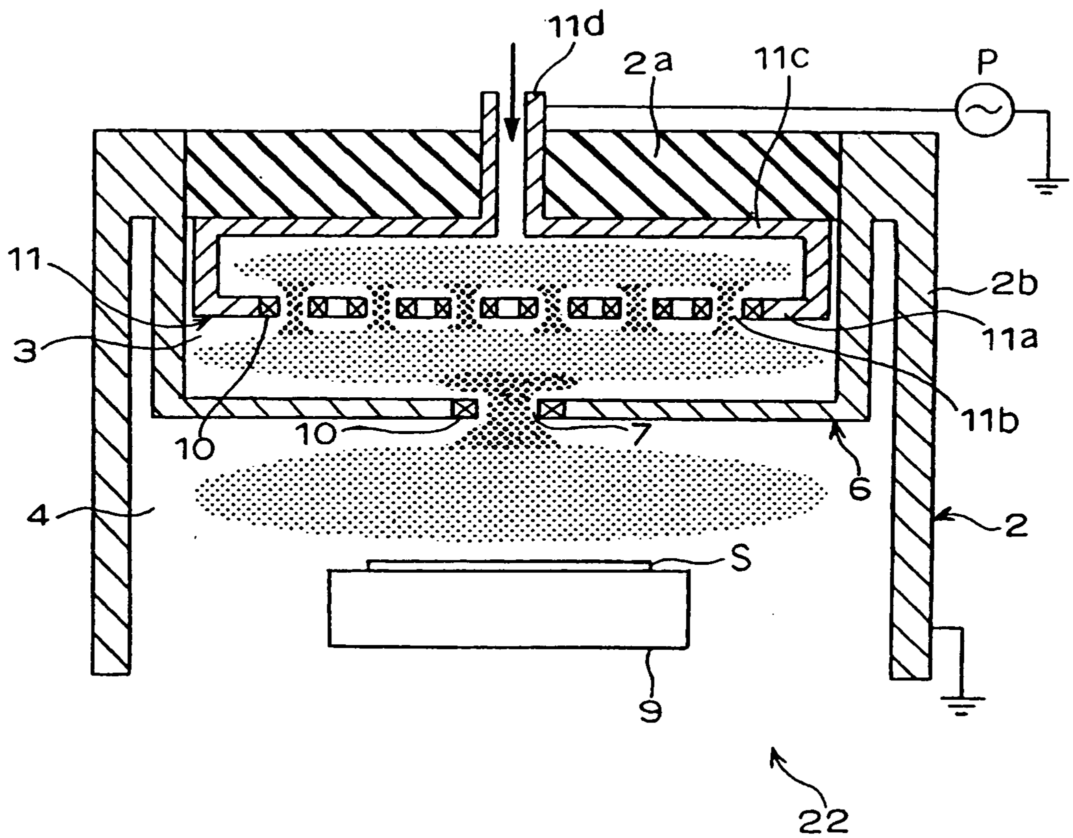
21	Surface treatment apparatus	11	Cathode electrode
2	Casing	11a	Lower wall section
2a	Upper wall	11b	Through hole
2b	Peripheral wall	11c	Upper wall section
3	Plasma generation chamber	11d	Gas inlet
4	Substrate treatment chamber	S	Substrate
6	Anode electrode	P	High frequency power supply
7	Plasma nozzle		

【図６】

第４実施例の装置の変形例によるカソード電極の概略図

[Fig. 6]

A schematic view of a cathode electrode according to a modification of the apparatus of the fourth embodiment.



２２	表面処理装置	１０	磁石
２	ケーシング	１１	カソード電極
２ａ	上壁	１１ａ	下壁部
２ｂ	周壁	１１ｂ	貫通孔
３	プラズマ発生室	１１ｃ	上壁部
４	基板処理室	１１ｄ	ガス供給口
６	アノード電極	Ｓ	基板
７	プラズマ吹出口	Ｐ	高周波電源

22	Surface treatment apparatus	10	Magnet
2	Casing	11	Cathode electrode
2a	Upper wall	11a	Lower wall section
2b	Peripheral wall	11b	Through hole
3	Plasma generation chamber	11c	Upper wall section
4	Substrate treatment chamber	11d	Gas inlet
6	Anode electrode	S	Substrate
7	Plasma nozzle	P	High frequency power supply

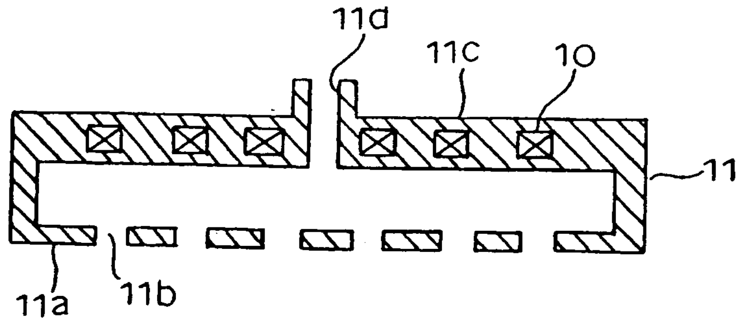
【図７】

第５実施例である表面処理装置の概略図

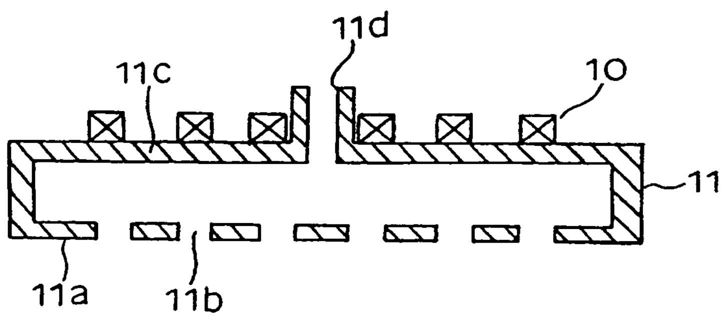
[Fig. 7]

A schematic view of a surface treatment apparatus according to a fifth embodiment.

(a)



(b)

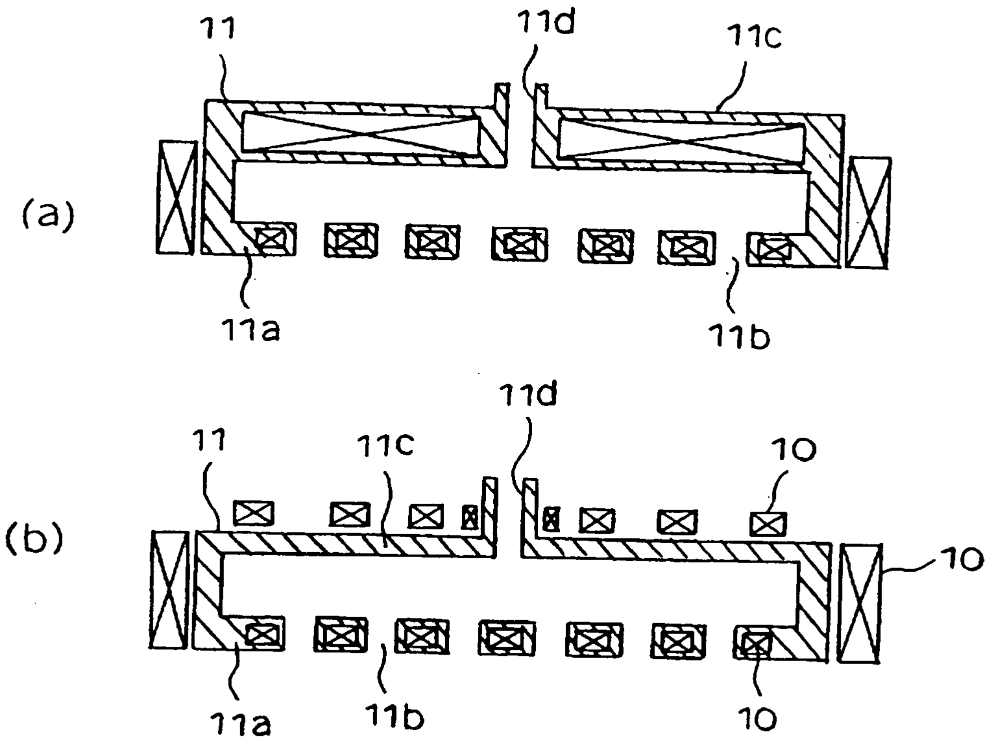


１０　磁石
１１　カソード電極
１１ａ　下壁部
１１ｂ　貫通孔
１１ｃ　上壁部
１１ｄ　ガス供給口

10 Magnet
11 Cathode electrode
11a Lower wall section
11b Through hole
11c Upper wall section
11d Gas inlet

【図８】

[Fig. 8]　　第６実施例である表面処理装置の概略図
Schematic views of surface treatment apparatuses according to a sixth embodiment.



１０　磁石
１１　カソード電極
１１ａ　下壁部
１１ｂ　貫通孔
１１ｃ　上壁部
１１ｄ　ガス供給口

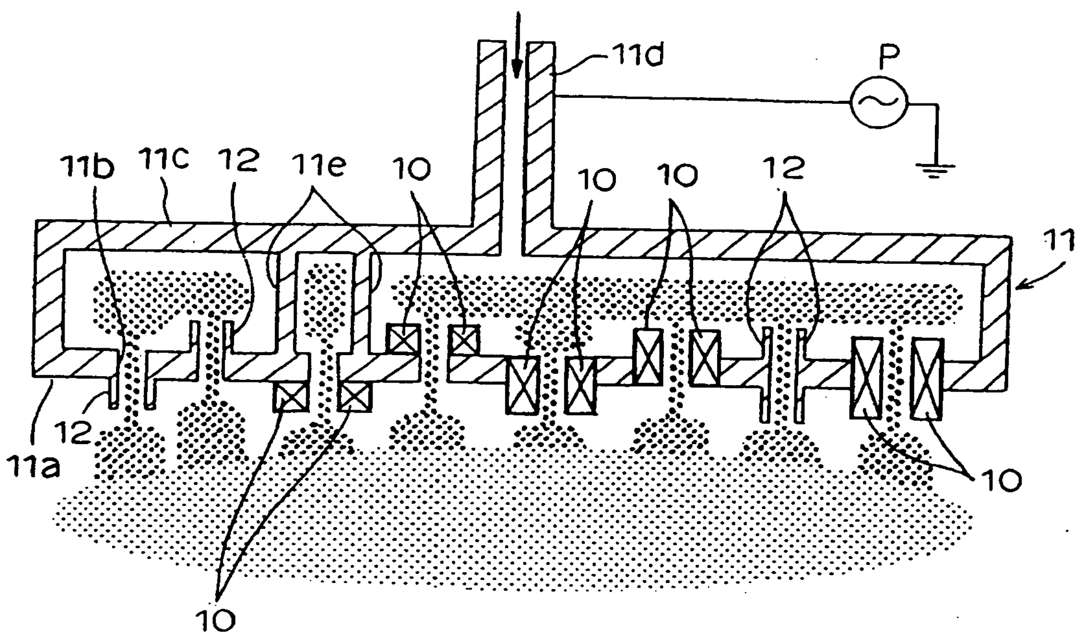
10 Magnet
11 Cathode electrode
11a Lower wall section
11b Through hole
11c Upper wall section
11d Gas inlet

【図９】

第７実施例である表面処理装置の概略図

[Fig. 9]

A schematic view of a surface treatment apparatus according to a seventh embodiment.



１０	磁石
１１	カソード電極
１１ａ	下壁部
１１ｂ	貫通孔
１１ｃ	上壁部
１１ｄ	ガス供給口
１１ｅ	隔壁
１２	ノズル体
Ｐ	高周波電源

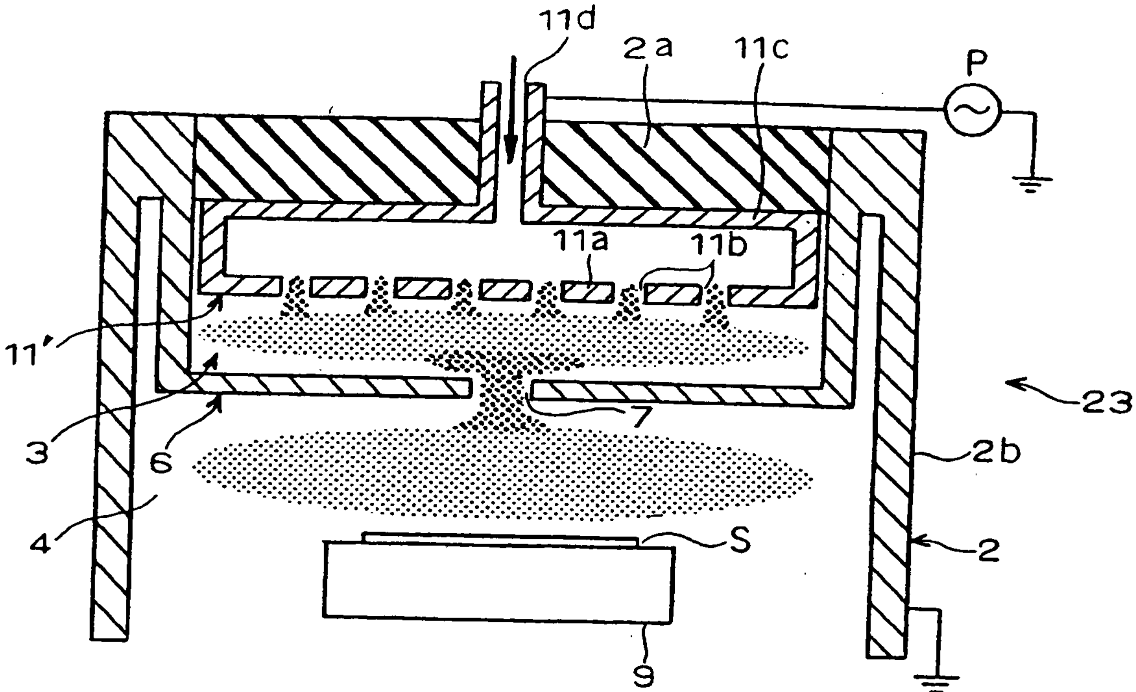
10	Magnet
11	Cathode electrode
11a	Lower wall section
11b	Through hole
11c	Upper wall section
11d	Gas inlet
11e	Partition wall
12	Nozzle element
P	High frequency power supply

【図１０】

第８実施例である表面処理装置の概略図

[Fig. 10]

A schematic view of a surface treatment apparatus according to an eighth embodiment.



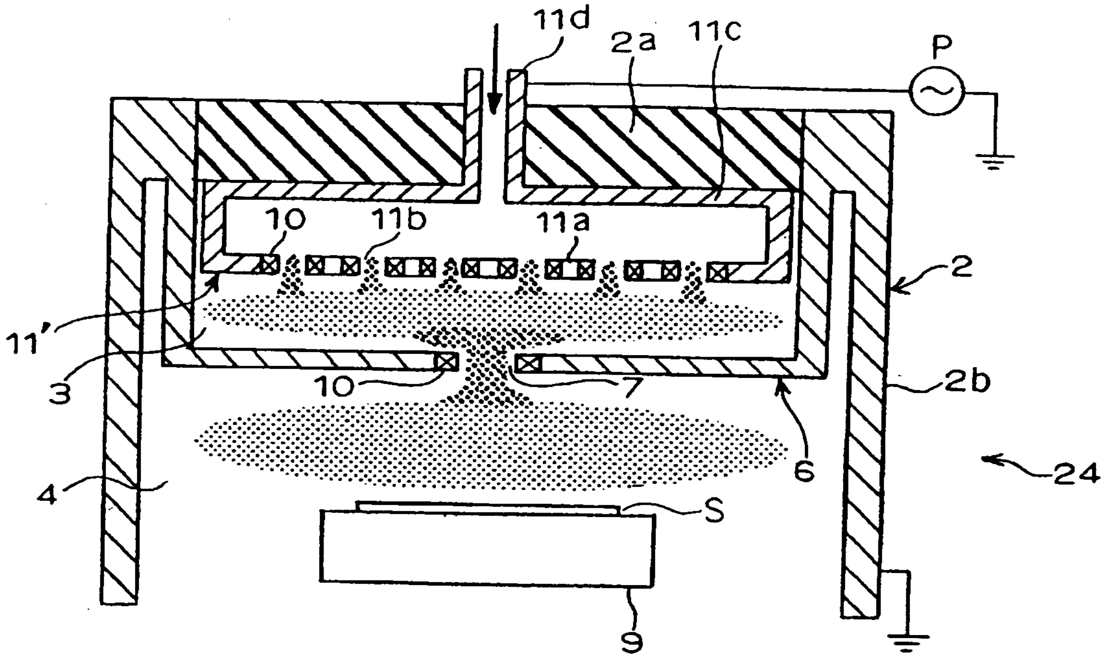
２３	表面処理装置	１１′	カソード電極
２	ケーシング	１１ａ	下壁部
２ａ	上壁	１１ｂ	貫通孔
２ｂ	周壁	１１ｃ	上壁部
３	プラズマ発生室	１１ｄ	ガス供給口
４	基板処理室	Ｓ	基板
６	アノード電極	Ｐ	高周波電源
７	プラズマ吹出口		
９	基板支持台		

23	Surface treatment apparatus	11	Cathode electrode
2	Casing	11a	Lower wall section
2a	Upper wall	11b	Through hole
2b	Peripheral wall	11c	Upper wall section
3	Plasma generation chamber	11d	Gas inlet
4	Substrate treatment chamber	S	Substrate
6	Anode electrode	P	High frequency power supply
7	Plasma nozzle		
9	Substrate support table		

【図１１】　[Fig. 11]

他の実施例による表面処理装置におけるカソード電極部分の概略図

A schematic view of a cathode electrode portion in a surface treatment apparatus according to another embodiment.

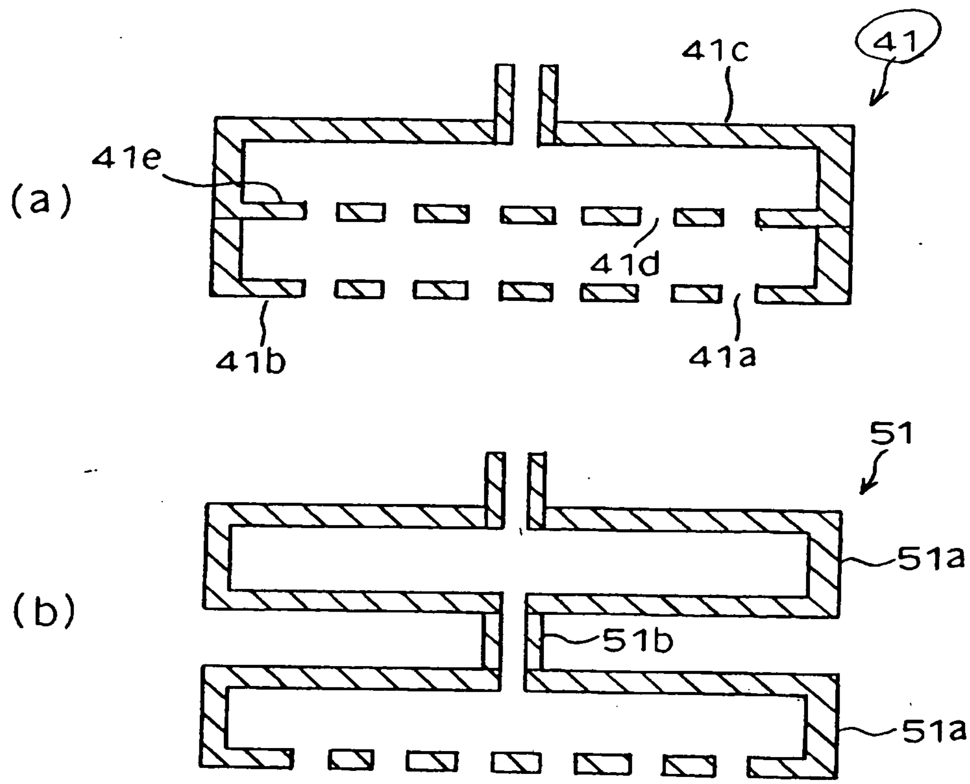


２４	表面処理装置	１０	磁石
２	ケーシング	１１′	カソード電極
２ａ	上壁	１１ａ	下壁部
２ｂ	周壁	１１ｂ	貫通孔
３	プラズマ発生室	１１ｃ	上壁部
４	基板処理室	１１ｄ	ガス供給口
６	アノード電極	Ｓ	基板
７	プラズマ吹出口	Ｐ	高周波電源
９	基板支持台		

24	Surface treatment apparatus	10	Magnet
2	Casing	11'	Cathode electrode
2a	Upper wall	11a	Lower wall section
2b	Peripheral wall	11b	Through hole
3	Plasma generation chamber	11c	Upper wall section
4	Substrate treatment chamber	11d	Gas inlet
6	Anode electrode	S	Substrate
7	Plasma nozzle	P	High frequency power supply
9	Substrate support table		

【図１２】

更に他の実施例による表面処理装置におけるカソード電極部分の概略図
[Fig. 12]
Schematic views of cathode electrode portions in a surface treatment apparatus according to still another embodiment.

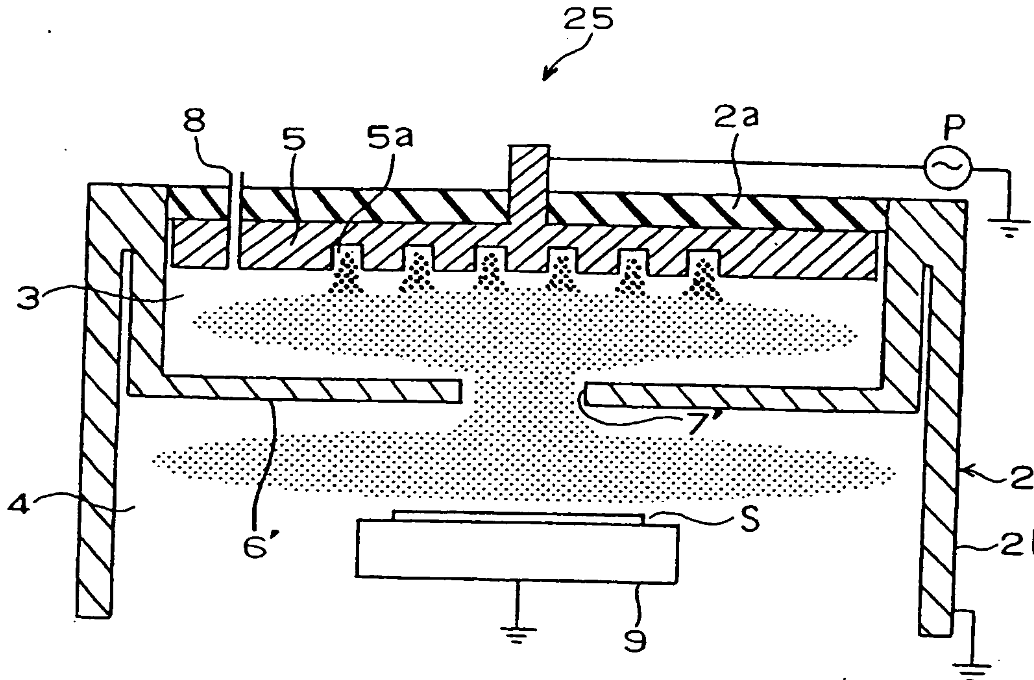


４１　カソード電極
４１ａ　下壁部
４１ｂ　貫通孔
４１ｃ　上壁部
４１ｄ　貫通孔
４１ｅ　仕切り壁
５１　カソード電極
５１ａ　中空電極部材
５１ｂ　連結口

41 Cathode electrode
41a Lower wall section
41b Through hole
41c Upper wall section
41d Through hole
41e Partition wall
51 Cathode electrode
51a Hollow-shaped electrode member
51b Communication opening

【図13】 [Fig. 13]

更に他の実施例による表面処理装置の水平方向の概略断面図
A horizontal schematic view of a surface treatment apparatus according to still another embodiment of the present invention.

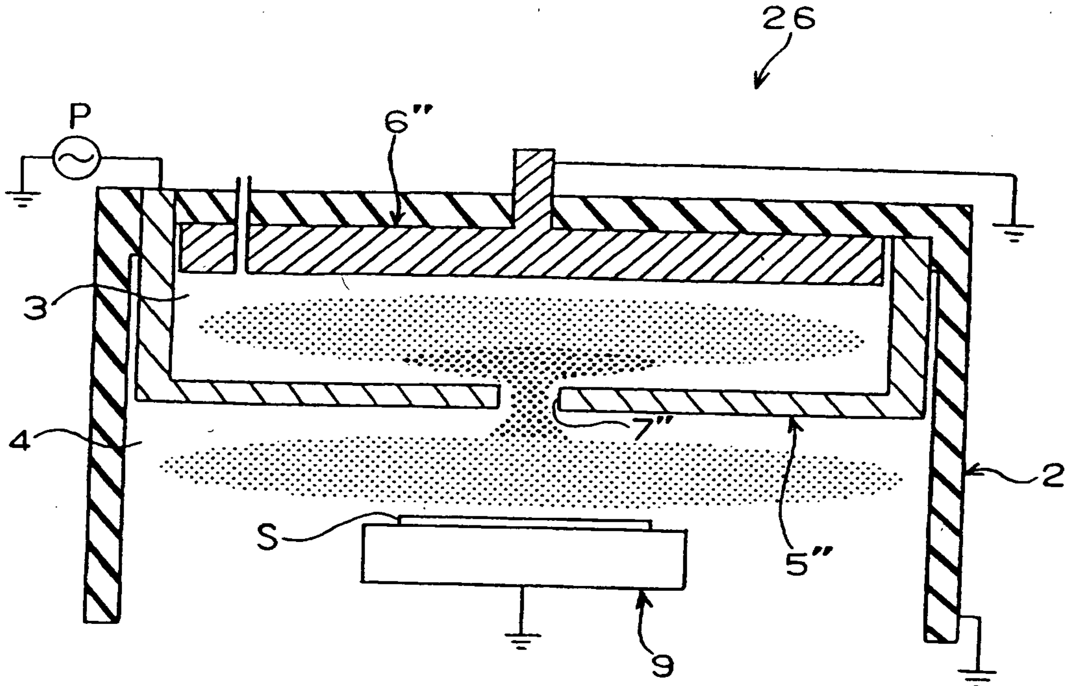


25	表面処理装置	5	カソード電極
2	ケーシング	5a	凹部
2a	上壁	6'	アノード電極
2b	周壁	7'	プラズマ吹出口
3	プラズマ発生室	8	ガス供給口
4	基板処理室	9	基板支持台
		S	基板
		P	高周波電源

25	Surface treatment apparatus	5	Cathode electrode
2	Casing	5a	Recess
2a	Upper wall	6'	Anode electrode
2b	Peripheral wall	7'	Plasma nozzle
3	Plasma generation chamber	8	Gas inlet
4	Substrate treatment chamber	9	Substrate support table
		S	Substrate
		P	High frequency power supply

【図１４】　[Fig. 14]

更に他の実施例による表面処理装置の水平方向の概略断面図
A horizontal schematic view of a surface treatment apparatus according to still another embodiment of the present invention.



２６	表面処理装置
２	ケーシング
３	プラズマ発生室
４	基板処理室
５"	カソード電極
６"	アノード電極
９	基板支持台
Ｓ	基板
Ｐ	高周波電源

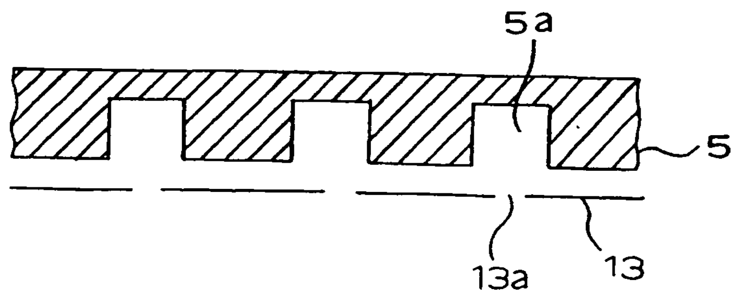
26	Surface treatment apparatus
2	Casing
3	Plasma generation chamber
4	Substrate treatment chamber
5"	Cathode electrode
6"	Anode electrode
9	Substrate support table
S	Substrate
P	High frequency power supply

【図１５】

更に他の実施例による表面処理装置の水平方向の概略断面図

[Fig. 15]

A horizontal schematic view of a surface treatment apparatus according to still another embodiment of the present invention.



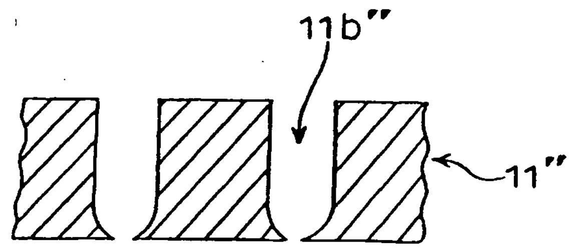
５　カソード電極
５ａ　凹部
１３　他の電極
１３ａ　小孔

5 Cathode electrode
5a Recess
13 Another electrode
13a Small hole

【図１６】

[Fig. 16]
A horizontal schematic view of a surface treatment apparatus according to still another embodiment of the present invention.

更に他の実施例による表面処理装置の水平方向の概略断面図



１１″　カソード電極
１１ｂ″貫通孔

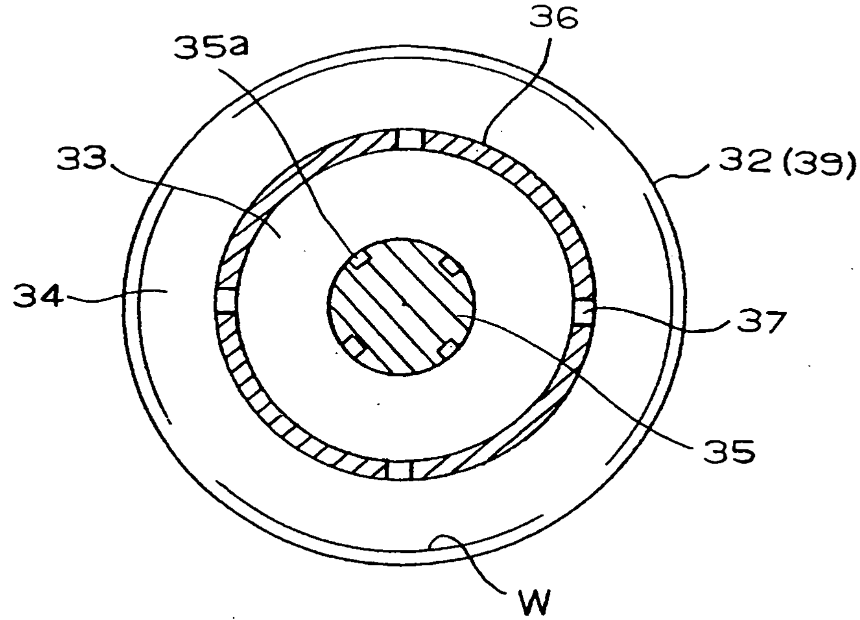
11" Cathode electrode
11b" Through hole

【図１７】

更に他の実施例による表面処理装置の水平方向の概略断面図

[Fig. 17]

A horizontal schematic view of a surface treatment apparatus according to still another embodiment of the present invention.



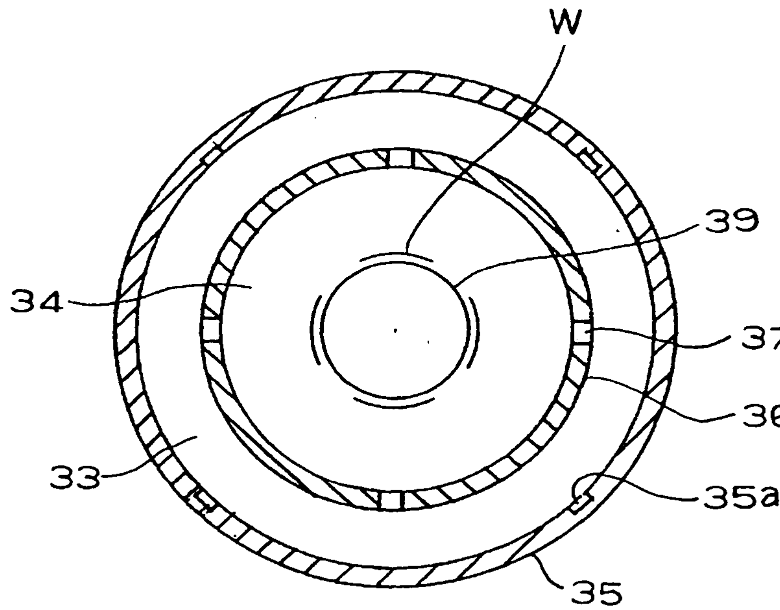
３２　ケーシング
３３　プラズマ発生室
３４　基板処理室
３５　カソード電極
３５ａ　凹部
３６　アノード電極
３７　プラズマ吹出口
３９　基板支持台

32 Casing
33 Plasma generation chamber
34 Substrate treatment chamber
35 Cathode electrode
35a Recess
36 Anode electrode
37 Plasma nozzle
39 Substrate support table

【図１８】　[Fig. 18]

更に他の実施例による表面処理装置の水平方向の概略断面図

A horizontal schematic view of a surface treatment apparatus according to still another embodiment of the present invention.



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３７　プラズマ吹出口
３９　基板支持台

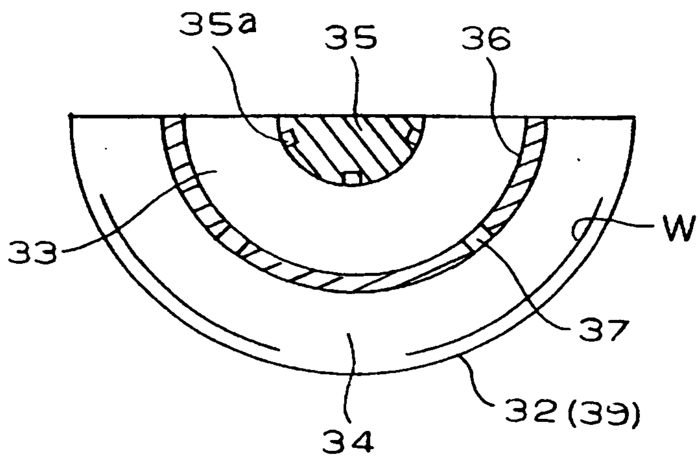
33　Plasma generation chamber
34　Substrate treatment chamber
35　Cathode electrode
35a　Recess
36　Anode electrode
37　Plasma nozzle
39　Substrate support table

【図１９】

他の実施例による表面処理装置の水平方向の概略断面図

[Fig. 19]

A horizontal schematic view of a surface treatment apparatus according to another embodiment of the present invention.



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３６　アノード電極
３７　プラズマ吹出口
３９　基板支持台

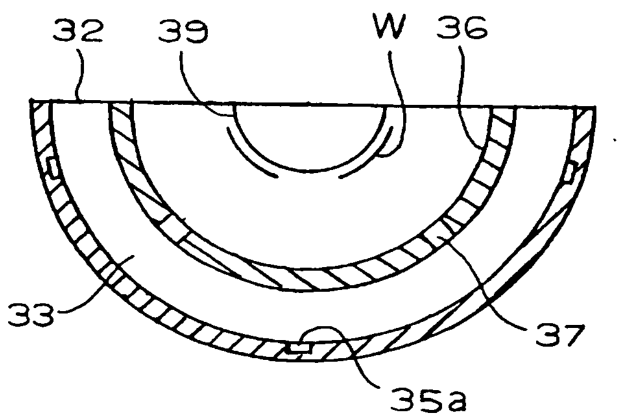
32 Casing
33 Plasma generation chamber
34 Substrate treatment chamber
35 Cathode electrode
35a Recess
36 Anode electrode
37 Plasma nozzle
39 Substrate support table

【図２０】

他の実施例による表面処理装置の水平方向の概略断面図

[Fig. 20]

A horizontal schematic view of a surface treatment apparatus according to another embodiment of the present invention.



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３６	アノード電極
３７	プラズマ吹出口
３９	基板支持台

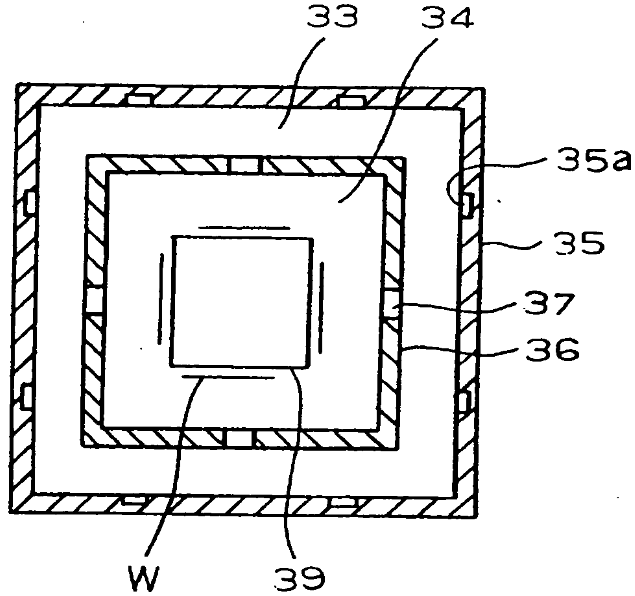
32	Casing
33	Plasma generation chamber
35a	Recess
36	Anode electrode
37	Plasma nozzle
39	Substrate support table

【図２１】

他の実施例による表面処理装置の水平方向の概略断面図

[Fig. 21]

A horizontal schematic view of a surface treatment apparatus according to another embodiment of the present invention.



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３５ａ　凹部
３６　アノード電極
３７　プラズマ吹出口
３９　基板支持台

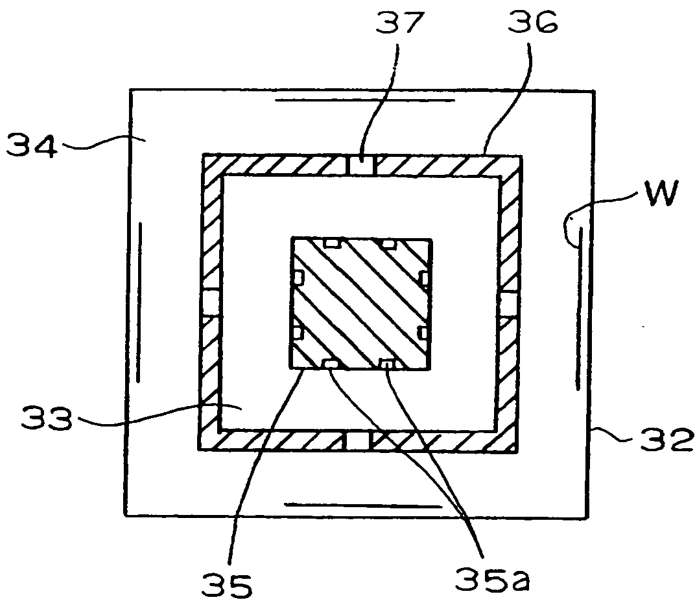
33 Plasma generation chamber
34 Substrate treatment chamber
35 Cathode electrode
35a Recess
36 Anode electrode
37 Plasma nozzle
39 Substrate support table

【図２２】

他の実施例による表面処理装置の水平方向の概略断面図

[Fig. 22]

A horizontal schematic view of a surface treatment apparatus according to another embodiment of the present invention.



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３５　カソード電極
３５ａ　凹部
３６　アノード電極
３７　プラズマ吹出口

32 Casing
33 Plasma generation chamber
34 Substrate treatment chamber
35 Cathode electrode
35a Recess
36 Anode electrode
37 Plasma nozzle

[DOCUMENT NAME] ABSTRACT

[Abstract]

[Object] To provide a surface treatment apparatus which can treat a surface with high speed and high quality.

[How to solve the problem] A casing (2) of a surface treatment apparatus (1) is defined into two chambers, a plasma generation chamber (3) provided with a plasma generation electrode (5, 6) and a substrate treatment chamber (4) provided with a substrate support table (9). A plasma nozzle (7) is formed on an anode electrode (6) constituting a partition wall of the both chambers (3, 4). A recess (5a) is formed on an upper cathode electrode (5). Further, the plasma nozzle (7) is used as a hollow anode discharge generation area, and the recess (5a) as a hollow cathode discharge generation area.

[Selected figure] Fig. 1